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OPERATIONAL ABORT PLAN FOR THE APOLLO 8 MISSION

Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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By Contingency Analysis Section
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OPERATIONAL ABORT PLAN FOR THE APOLLO 8 MISSION

By Contingency Analysis Section

1.0 SUMMARY

A continuous method of returning the flight crew safely to earth for the Apollo 8 mission - with or without ground control help - has been defined. The rationale and supporting data are given. These supporting data consist primarily of (1) maneuver monitoring techniques and limits used to protect against known constraints, and (2) abort trajectory data produced by computer simulations of the recommended abort procedures.

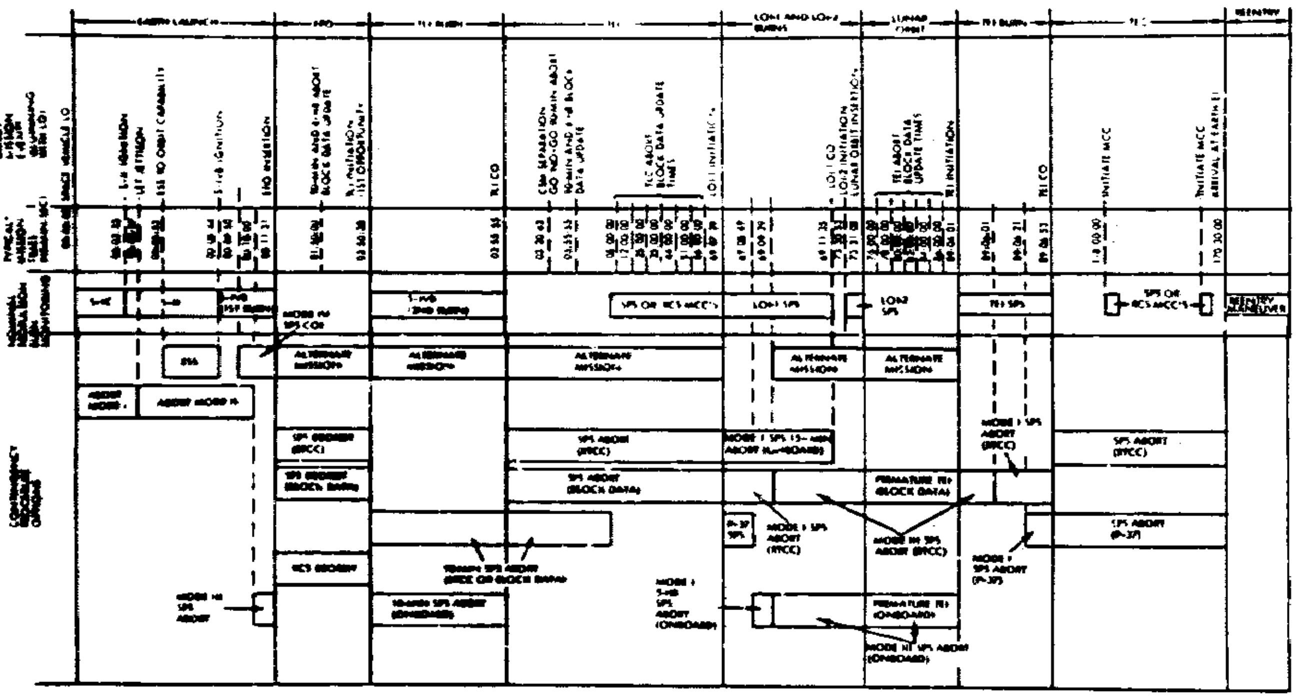
2.0 INTRODUCTION

The purpose of this document is to demonstrate that an adequate abort plan exists for all mission phases of the first manned Apollo Saturn flight to the moon, the Apollo 8 (C', Alternate 1) mission. In addition, it presents information that could be used by ground controllers and the crew to provide safe abort capability for a December 21, 1968 launch date and a 72° flight azimuth. Variations in the information in this document due to changes in the launch azimuth and monthly launch window will be included in a later document.

Of particular importance is the relationship of the various methods of aborting described in this document and the capability to abort at any time, normally provided by RTCC and ground control procedures. This relationship is best illustrated by figure 2-1, which also indicates the failure level from the nominal mission required before a particular abort mode would be used. It is seen that most crew-determined abort circumstances occur during a powered-flight phase of the mission, which requires that nominal maneuver monitoring procedures provide the necessary safety constraints to insure abort capability. Detailed ground and crew procedures for all methods of abort required for this mission are presented in references 1 and 2. This document consists primarily of abort trajectory data which would result from aborting with each of the methods identified in figure 2-1. In general, these are abort methods which the crew can use without help from the ground. Also, this abort plan shows that a procedure and the required data will be available throughout the Apollo 8 mission if a contingency should arise. Launch phase and TLI trajectory information was obtained from reference 3, and the nominal spacecraft trajectory characteristics were obtained from reference 4.

Input constants common to the analyses of the phases of the mission are presented in appendix A.

The Contingency Analysis Section is conducting an analysis to determine the limitations on RCS aborts from the nominal and dispersed TLI burns. Appendix B presents pertinent data now available for the nominal trajectory.



*DECEMBER 21, 1968 LAUNCH - 72 DEG AZIMUTH

Figure 2-1.- The relationship of the nominal Apollo 8 mission events and operational abort modes.

3.0 ABBREVIATIONS

ACRA	Atlantic continuous recovery area
ADRA	Atlantic discrete recovery area
AOL	Atlantic Ocean line (recovery)
c.g.	center of gravity
CDR	commander
CLA	contingency landing area
CM	command module
CMC	CM computer
COI	contingency orbit insertion
CSM	command and service modules
DSKY	display keyboard
EMS	entry monitoring system
EPL	Eastern Pacific line (recovery)
EPO	earth parking orbit
EOI	earth orbit insertion
ESS	early S-IVB staging
g	entry load
g.e.t.	ground elapsed time
G.m.t.	Greenwich mean time
FCUA	fuel-critical unspecified area
FDAI	flight director attitude indicator
I_{sp}	specific impulse

IGA	inner gimbal angle
IMU	inertial measurement unit
IOL	Indian Ocean line (recovery)
L/D	lift-to-drag ratio
LET	launch escape tower
LEV	launch escape vehicle
LM	lunar module
LOI	lunar orbit insertion
LOI 1	LOI into a 60- by 170-n. mi. altitude orbit
LOI 2	lunar orbit circularization burn into a 60- by 170-n. mi. altitude orbit
LPO	lunar parking orbit
LTAB	lunar test article B
LV	launch vehicle
MCC	midcourse correction
MCC-H	Mission Control Center - Houston
MGA	middle gimbal angle
MNVS	multi-vehicle N-stage computer program
MPL	mid-Pacific line (recovery)
MSI	moon's sphere of influence
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
NPV	nonpropulsive vent
NR	North American Rockwell
OGA	outer gimbal angle

P-11	CMC program 11
P-36	CMC program 36 (return to earth)
PGNCS	primary guidance, navigation, and control system
r	radius
R_{lp}	predicted full-lift landing range from the launch pad
RCS	reaction control system
REFSMMAT	transformation matrix from inertial to stable member (IMU)
RTCC	Real-Time Computer Complex
SC	spacecraft
SCS	stabilization and control subsystem
SCT	scanning telescope
S-IVB	launch vehicle third stage
SLA	spacecraft LM adapter
SM	service module
SPS	service propulsion subsystem
T_{ff}	time off free fall
T	lift-off
T_{ig}	time of ignition
TAR	time from abort to reentry
TB_7	time base 7 - initiated at TLI cutoff
TEC	transearth coast
TEI	transearth injection
TFT	total flight time from TLI, LOI, or TEI shutdown to landing

TH	thermal control
TLC	translunar coast
TLI	translunar injection
USBS	Unified S-band System
WPL	West Pacific line
ΔR	difference between the onboard predicted landing point and the mode III target point
ΔV	total sensed velocity change

4.0 GUIDELINES AND CONSTRAINTS

This document is based on a number of fundamental guidelines and constraints of which the most important are listed below:

1. An abort is defined as the recognition and performance of those conditions necessary to terminate the current mission and return the flight crew to earth.

2. An alternate mission is defined as the continuation of the flight usually with less ambituous objectives than originally planned.

3. Return-to-earth abort maneuvers are normally targeted to CLA's. The CLA's for the Apollo 8 mission are shown in figure 4-1.

4. Aborted mission return times are consistent with known system constraints and generally are optimized to provide the fastest return for the least ΔV.

5. The maximum velocity required for an abort will not exceed 10 000 fps.

6. Return-to-earth inclinations will not exceed 40°.

7. The inertial velocity at entry will not exceed 36 333 fps.

8. All planned abort maneuvers normally use the external ΔV steering mode.

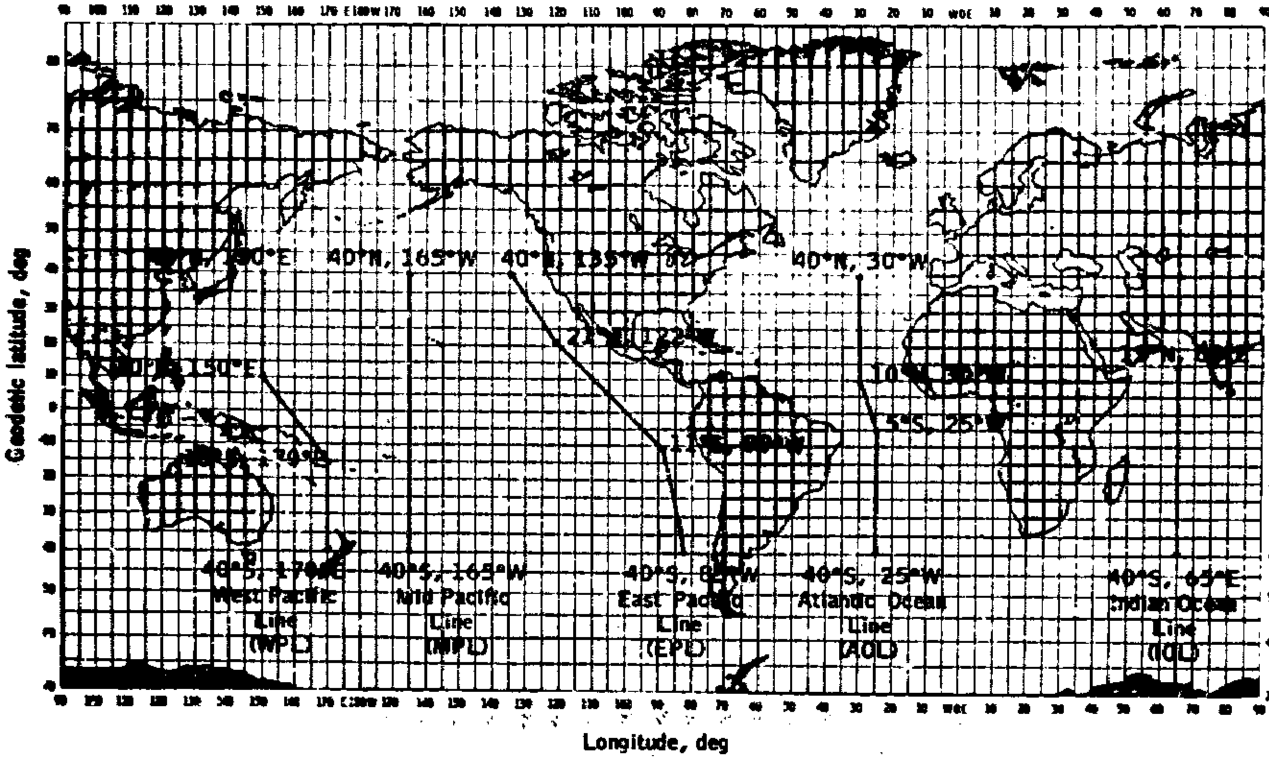


Figure 4-1.- Apollo 8 contingency landing areas.

5-1

LAUNCH PHASE

5.0 LAUNCH PHASE

The launch abort trajectory data shown provides information on abort monitoring, abort maneuver requirements, and abort results. It is assumed that the launch vehicle performance can vary over a wide range of conditions during launch. Therefore, these conditions must be bounded by limits that would allow sufficient reaction time by the crew and spacecraft systems operations to perform a safe abort. To prevent a flight with unsafe conditions abort action would be initiated if the launch vehicle violates these limits. To avoid aborting a successful launch, the limit lines are defined for the least restrictive conditions which will allow a safe abort.

During launch the velocity, altitude, atmosphere, and launch configuration change drastically; therefore, several abort modes, each adapted to a portion of the launch trajectory, are required:

1. Mode I aborts protect the SC and crew while the LV is on the pad and in atmospheric flight. They utilize the launch escape system for safe separation, and the aborts result in a suborbital trajectory with landings in the ACRA.

2. Mode II abort capability begins once the LET has been jettisoned (187 seconds g.e.t.) and continues until the COI capability begins (V_i = 23 600 fps) or until the resulting landings threaten the African coast (R_{ip}[a] = 3200 n. mi.). Mode II aborts consist of a manual CSM separation from the LV, CM/SM separation, an entry orientation maneuver, and an open-loop, full-lift entry. These aborts result in a suborbital trajectory with landings in the ACRA also.

3. The mode III abort capability begins once the mode II ends and continues until the maneuver violates free-fall time (approximately 2 seconds prior to the first S-IVB cutoff signal at 680 seconds g.e.t.) The mode III aborts consist of a manual CSM separation, a fixed-attitude SPS retrograde burn, CM/SM separation, an entry orientation maneuver, and an open-loop, bank-left 55° entry. These abort maneuvers result in a suborbital trajectory with landings at the ADRA approximately 3350-n. mi. down range of the launch pad, just south of the flight azimuth.

4. Mode IV, i.e., COI capability or apogee kick, begins once the SPS can be used to insert the CSM into a safe orbit (V_i = 23 600 fps)

[a] R_{ip} is the predicted full-lift landing range from the launch pad.

and continues until the LV has obtained a safe orbit. The COI maneuver consists of a manual CSM separation, a fixed-attitude, posigrade SPS burn which results in at least a 75-n. mi. perigee altitude, and subsequent SPS deorbit to a planned landing area. These maneuvers result in a safe orbital trajectory from which an alternate mission or an immediate deorbit can be planned.

These launch abort mode capabilities are summarized on a bar chart, figure 5-1, for the nominal 72° launch azimuth, December 21 timeline. Also shown is the early S-IVB staging (ESS) capability region, which defines when the S-IVB can direct stage from the S-II (353 seconds g.e.t.) and still achieve a parking orbit.

The launch abort data shown here is consistent with the latest Apollo 8 (Alternate 1) characteristics and is for aborts from the nominal 72° azimuth launch trajectory. A detailed analysis for CSM aborts (modes II, III and IV) from a typical Saturn V launch trajectory which shows the effects of variable launch azimuth, is shown in reference 5. That data is directly applicable to this mission and can be used to estimate the effects of variable azimuth on the launch abort modes. The sensitivities of the various launch abort parameters for variations in weight, altitude, burn attitude, and other parameters are discussed in reference 6. Another document that should be used to supplement the launch abort information presented is reference 2. This reference presents the launch phase abort techniques and data flow for the Saturn V Apollo launches. It contains the flow charts and accompanying rationale for the abort cues, decisions, and data flow for each of the abort modes.

5.1 Launch Trajectory Monitoring

5.1.1 Ground monitoring.- The ground (MCC-H) flight controllers have the primary responsibility of monitoring the trajectory during the launch phase. The ground is prime for determining abort trajectory limit violations, abort mode decisions, and the GO - NO-GO orbit insertion status. To aid the ground's trajectory monitoring are the flight dynamics displays. These consist of the launch digitals and projection plotters displayed on cathode ray tubes and analog plotboards. The displays are driven by real-time computer computations based on the actual flight data received from the MSFN. The Flight Dynamics displays currently being used in Apollo 8 simulation are presented in reference 7. These displays will be similar for all the planned Saturn V launches and are defined in reference 5.

The launch abort trajectory limits are summarized on figure 5-2. These limits include a structural breakup limit, 16g limit, a 100-second free-fall time limit, and a potential exit heating limit (currently under

investigation at NR). These limits define a launch corridor that is acceptable for safe SC abort capability. In addition to the limits and the nominal trajectory, the S-IVB early staging and the SPS COI capability lines are shown. The latter two lines define, respectively, when the S-II has progressed sufficiently for the S-IVB to direct stage into a parking orbit (100 n. mi., circular) and when the S-IVB has progressed enough for the SPS (mode IV) to insert the SC in contingency orbit (h_p > 75 n. mi.).

Comparing the COI capability with the suborbital capability for the near-insertion region, the abort mode overlap can be determined. This is shown on figure 5-3 and, as can be seen, the mode IV COI capability overlaps the end of mode II and all of mode III along the nominal trajectory. Also shown are the dispersed S-IVB cutoff conditions that would require a mode III or apogee kick maneuver. The 75-n. mi. perigee altitude line is shown to indicate when the S-IVB has achieved a GO orbit and a 500-n. mi. apogee line is shown to indicate an S-IVB overspeed condition. Note that mode III capability is limited by a 100-second t_{ff} constraint and increased insertion ranges would further restrict the mode III capability. Therefore, large mode III SPS burns could be terminated on the 100-second t_{ff} limit prior to achieving the landing target. Zero lift (roll left 90°) is recommended for those cases that require premature termination.

The trajectory lines shown on figures 5-2 and 5-3 are analogous to the plotboard information being displayed to the flight controllers in real time. Comparing the actual launch trace with this trajectory information will aid the flight controllers in determining the trajectory status during launch and to determine the appropriate abort mode, if necessary. The ground will keep the crew informed on the trajectory status by voice communications and request abort action by both voice and the abort light upon abort confirmation.

5.1.2 Onboard monitoring.- During launch, the crew has CMC program P-11 and its corresponding DSKY displays, and the FDAI displays to facilitate trajectory monitoring. P-11 is automatically initiated upon lift-off (or manually by V75E) and is available until the ground or crew commands program 00. Normally the ground will inform the crew of their trajectory status. However, if voice communications were lost during the launch, the crew would have to depend on these displays for this information. Table 5-I shows the values of the DSKY parameters for a nominal launch, which were computed with the COLOSSUS guidance equations (ref. 8) for Apollo 8. The nominal FDAI attitudes during the launch are shown on figure 5-9. The DSKY displays are updated every two seconds and displayed to the crew. Any time the ground should rule the SC guidance NO-GO, the computer would be commanded to program 00 and these DSKY displays would no longer be available.

In conjunction with the DSKY displays associated with P-11 (fig. 5-4), two onboard charts (figs. 5-5 and 5-6) are proposed for use in the event of voice communications loss during the launch. The basic DSKY displays for launch monitoring are the inertial velocity, V_i, altitude rate, $\dot{h}$, and altitude, h, parameters. Therefore, these are the parameters used to govern the charts. The charts with the DSKY are to be used to help determine when and what abort action is necessary. These functions would normally be conducted by the ground when voice communications exist. Once the abort decision has been made, the crew would use the DSKY parameters to monitor the abort burn. The mode III and IV SPS burn ignition times are for 125 seconds after S-IVB cutoff; other ignition times would be incompatible with the COI capability shown on the onboard chart and with burn verification runs made by the ground. If TFF becomes equal to 100 seconds and is decreasing during a burn, the burn must be terminated and immediate entry preparation initiated. Caution should be employed during the mode IV burn. If anytime during the burn perigee altitude starts decreasing, the burn should be terminated; and if terminated with $h_p < 75$ n. mi., a mode III abort should be initiated when $\dot{h} \leq 0$ or $h_a < 75$ n. mi. and an apogee kick should be initiated when $\dot{h} > 0$.

Chart 1, shown on figure 5-5, shows the nominal altitude rate versus velocity trace and the current abort trajectory limits. Should the actual flight trace violate the booster breakup line or the maximum entry load limit line (16g), an abort is required. If the trace approaches the t_{ff} limit line, V82E and N50E should be called and abort action is taken when t_{ff} equals 100 seconds and is decreasing. Note that even if voice communications were lost, the ground might still be able to command abort action by using the abort light. Because of the sensitivity of the 16g limit line to altitude, this limit is shown for several different altitudes, and the current altitude displayed on the DSKY would govern which abort limit to use.

Chart 2, shown on figure 5-6, shows the nominal altitude rate versus velocity trace for approximately the last 2 minutes of the launch. This chart expands the region where abort capability starts varying rapidly. The primary use of this chart is to show for what S-IVB cutoff conditions COI capability exists. Therefore, the COI boundary is defined for different altitudes. Since the altitude is fairly static near insertion, the crew could choose the appropriate COI boundary and determine when the S-IVB trace crosses into the COI capability region. The other abort capabilities can be determined directly from the DSKY. Once tower jettison has occurred, mode II capability extends until ΔR[a] becomes greater than -368 n. mi., which corresponds to a full-lift landing at

[a] ΔR, or SPLERROR, is the difference between the onboard predicted landing point and the mode III target point.

3200 n. mi. S-IVB cutoff conditions resulting in a ΔR of between -368 and 0 n. mi. when a suborbital abort is required indicate a no-burn, half-lift entry abort procedure; for $\Delta R > 0$, a mode III burn is required. A GO orbit is achieved when perigee altitude is greater than or equal to 75 n. mi.

Note whenever the t_{ff} is 59 minutes 59 seconds, the ΔR computation is invalid. This is true once the perigee altitude becomes greater than 300 000 ft. If a mode III burn is required in this region, ΔR will become valid when the burn has progressed enough to decrease perigee altitude below 300 000 ft.

The effects of varying launch azimuth in the ΔR computation are currently under investigation. Because the ΔR computation is based on the mode III target (ADRA) being loaded prelaunch, this computation would be erroneous for launches on other than the planned launch azimuth. The need, frequency, and procedure for updating this target will be determined in this study.

5.2 Input Data

5.2.1 Launch vehicle trajectory and characteristics.- The launch abort information enclosed was generated based on the initial conditions taken from a launch trajectory listing of MSFC's B7 tape (EPO, 72° launch azimuth) for Apollo 8, as defined in reference 3. The initial abort conditions (LV shutdown) are assumed coincident with the printout on the launch trajectory for that time of abort, and the LV tailoff (ref. 9) is simulated prior to SC separation. Flight-path angle and altitude dispersions were simulated by varying these parameters at the time of abort and holding the other parameters constant.

The nominal trajectory parameters for this launch are shown on figures 5-7, 5-8, and 5-9. The variation of the inertial velocity, inertial flight-path angle, altitude, and down-range distance with ground elapsed time are presented on figures 5-7 and 5-8. The SC IMU gimbal angle readouts for the nominal launch are presented on figure 5-9. These plots represent the main initial conditions simulated for these launch abort trajectories.

5.2.2 Spacecraft characteristics and trajectory constants.- CM aerodynamics were defined for Apollo 8 beginning-of-mission c.g. location as well as SC mass properties from reference 10.

Earth model constants and S-band tracking station locations for manned Apollo missions were taken from references 11 and 12, respectively. The launch pad (39A) location was taken from reference 13. The entry

interface altitude is 400 000 ft, and the reference altitude for the t_{ff} calculation in the launch phase is 300 000 ft.

The SC attitude for the mode III, mode IV, and apogee kick SPS burns are consistent with the scribe mark positioned on the command pilot's window. The angle between the line of sight along the scribe mark and the CSM X-body axis is 31.7° (ref. 14). This scribe mark is lined up with the horizon at burn ignition. During an SPS burn the thrust axis is aligned through the c.g. and, for the launch abort burns, is held inertially fixed (SCS automatic) throughout the burn. These simulations assumed that the thrust axis was oriented through the SPS thrust vector null offset position (2.15° pitch, ref. 15). This alignment will be updated to the actual c.g. for the final mission support data. The yaw error corresponding to this thrust vector offset is considered negligible for this analysis.

The mode II, mode III, and COI trajectories were simulated with the multi-vehicle N-stage (MVNS) computer program defined in reference 16. This program has the capability to simulate both powered and coasting flight. For these studies vehicle rotational dynamics do not have any significant effect and were not investigated.

5.3 Suborbital Aborts

5.3.1 Mode I LEV aborts.- The possibility of mode I LEV aborts from the Saturn V vehicle launched from complex 39A exists from the time the LEV is armed until tower jettison at approximately 3 minutes 7 seconds g.e.t.

The LEV is designed to accelerate the CM away from the LV to a safe separation distance and far enough down range from the launch pad for a safe water landing. Mode I aborts are divided into three categories: mode Ia (low altitude), mode Ib (medium altitude), and mode Ic (high altitude).

This analysis used the Apollo 8 LV operational flight trajectory (ref. 3) and the CSM/LM spacecraft operational data book (ref. 10). The LEV configuration is presented in figure 5-10.

The following is a summary of the mode I LEV abort sequences.

(a) Mode Ia (0 to 42 seconds g.e.t.)

T = 0 seconds	fire launch escape motor and pitch control motor
T + 11 seconds	deploy canards
T + 14 seconds	jettison tower and boost-protective cover
T + 14.4 seconds	jettison apex cover
T + 16 seconds	deploy drogue chutes
T + 28 seconds	deploy main chutes if the g.e.t. < 37 seconds
10 500-ft altitude	deploy main chutes if the g.e.t. ≥ 37 seconds

(b) Mode Ib (end of mode Ia to 108 seconds g.e.t., or approximately 100 000-ft altitude)

T = 0 seconds	fire launch escape motor, pitch control motor is not ignited after 42 seconds
T + 11 seconds	deploy canards

If g.e.t. < 64 seconds:

T + 14 seconds	jettison tower and boost-protective cover
T + 14.4 seconds	jettison apex cover
T + 16 seconds	deploy drogue chutes
10 500-ft altitude	deploy main chutes

If g.e.t. ≥ 64 seconds:

23 300-ft altitude + .01 seconds	jettison tower and boost-protective cover

23 300-ft altitude + 0.41 seconds	jettison apex cover
23 300-ft altitude + 2 seconds	deploy drogue chutes
10 500-ft altitude	deploy main chutes

(c) Mode Ic (end of mode Ib to 187.4 seconds or tower jettison time)

T = 0 seconds	fire launch escape motor
T + 11 seconds	deploy canards and manually establish + 5 deg/sec pitch rate with CM RCS
23 300-ft altitude + .01 seconds	jettison tower and boost-protective cover
23 300-ft altitude + 0.41 seconds	jettison apex cover
23 300-ft altitude + 2 seconds	deploy drogue chutes
10 500-ft altitude	deploy main chutes

Table 5-II presents a summary of Apollo 8 mode I LEV abort trajectories (no winds) for a nominal launch trajectory of 72° flight azimuth.

Figures 5-11 and 5-12 show the mode I nominal abort landing points. All of the landing points have safe water landings.

Mode I LEV aborts with no winds for the Apollo 8 mission have safe water landings from near the pad to approximately 520-n. mi. down range. The mode I LEV abort data presented in this document are considered adequate for positioning recovery forces and do not violate any known spacecraft constraints.

5.3.2 Mode II aborts.- The mode II abort procedures are designed for contingencies occurring after the LET jettison (187 seconds g.e.t.) until a safe orbit can be achieved with the SPS (590 seconds g.e.t.) or until the resulting landings threaten the west coast of Africa (R_{ip} = 3200 n. mi.). Because the aborts initiated in this region can

result in high entry loads (g's) and/or time-critical entries, no range control maneuvers are considered. A full-lift entry is used to minimize g's, and a simple separation technique is established for rapid entry orientation. The mode II procedure requires at least a 100-second t_{ff} from S-IVB cutoff to 300 000-ft altitude to orient to the proper atmospheric capture attitude. For low launch trajectories, this sometimes requires extending the mode I region by delaying tower jettison until sufficient free-fall time is available to perform the mode II abort.

The sequence of events simulated for a mode II abort are listed below:

T + 0 sec	LV shutdown and tailoff begins
T + 3 seconds	LV/CSM separation +X SM/RCS ON (4 jet)
T + 24 seconds	+X SM/RCS OFF start CM/SM separation sequence and orient CM to entry attitude
g = 0.05	CM oriented for full-lift entry (fig. 5-13)
h = 23 500 ft	drogue parachute deploys

A list of the pertinent trajectory parameters for mode II aborts from the nominal launch trajectory are presented in table 5-III. The spacecraft IMU gimbal angles corresponding to the proper CM entry orientation attitude for mode II aborts are presented versus time of abort in figure 5-13. A more detailed analysis of the mode II aborts for the Saturn V launches is presented in reference 5.

5.3.3 Mode III aborts.- The mode III abort procedures are required for contingencies occurring beyond mode II (R_{ip} > 3200 n. mi.) when a safe orbit cannot be achieved or when SC systems malfunctions dictate immediate landings. The first mode III requirement is unlikely because of the large COI region and the S-IVB cutoff conditions would have to be greatly dispersed from the nominal launch trajectory. The second is unlikely because if such a malfunction had occurred during launch, the abort would more probably be initiated before entering mode III, and failures occurring after entering mode III would be almost impossible to confirm in sufficient time to recommend a mode III abort. These type failures are undefined at present.

The sequence of events simulated for a mode III abort are listed below:

T + 0 seconds	LV shutdown and tailoff begins
T + 3 seconds	S-IVB/CSM separation +X CM RCS ON (4 jet)
T + 24 seconds	+X SM RCS OFF start orientation to SPS retrograde attitude if burn required
T + 125 seconds	retrograde attitude obtained (fig. 5-14) SPS engine ignition (FCS automatic)
Half-lift landing range = 3350 n. mi.	start CM/SM separation sequence and orient CM to entry attitude; SPS burn terminates
g = 0.05	CM oriented for full-lift entry; capture attitude [fig. 5-16(a)]
g = 0.2	CM oriented for half-lift entry; RL55 [fig. 5-16(b)]
h = 23 500 ft	drogue parachute deploys

Mode III abort capability begins at the end of mode II when the full-lift landing range (R_{lp}) exceeds 3200 n. mi. (600 seconds g.e.t.). Since mode III entries are half lift (RL55) and the SPS retrograde burn is only required to achieve a landing range of 3350 n. mi., there exists a period (between 600 and 624 seconds g.e.t.) for which the no-burn landing would land west of the 3350-n. mi. landing target (ADRA). The mode III capability ends once the required SPS burn violates the 100-second t_{ff} constraint. This occurs approximately 2 seconds prior to the S-IVB cutoff signal, and suborbital aborts required after that time would require terminating the burn on t_{ff} = 100 seconds and then a zero lift (RL90) entry to avoid a land landing.

A list of the pertinent trajectory parameters for mode III aborts from the nominal launch trajectory are presented on table 5-IV. The SC IMU gimbal angles corresponding to the horizon monitor (31.7° scribe mark) retrograde SPS burn attitude are presented on figure 5-14 for mode III aborts from the nominal trajectory. The mode III ΔV requirements to achieve landings at the ADRA are shown on figure 5-15 for deviations from the nominal flight-path angle and altitude. Note from these figures that the mode III region is bounded by the end of mode II, 16g entry load limit, and the 100-second t_{ff} limit. On figures 5-16(a) and 5.16(b) the proper capture and bak angles are shown for the half-lift entries required for the mode III aborts from the nominal LV trajectory.

A more detailed analysis of the mode III aborts for the Saturn V launches is presented in reference 5.

5.4 Contingency Orbit Insertion

5.4.1 <u>Mode IV COI procedure</u>.- The mode IV COI procedure is selected for contingencies once the SPS can insert the SC into a safe orbit (perigee altitude $\geq$ 75 n. mi.) and deorbit from any place in the resulting orbit. This capability begins at 590 seconds ($V_i \approx$ 23 600 fps) and ends once the S-IVB has achieved a safe perigee, approximately 680 seconds, or 2 seconds prior to nominal S-IVB cutoff signal. COI is the prime selection whenever the capability exists because it is the safest and has potential alternate mission capability. It allows the ground and crew ample time in earth orbit to determine the SC's trajectory and system status, and the ground can compute a precise deorbit maneuver for a planned landing area.

The sequence of events simulated for a mode IV maneuver are listed below:

T + 0 seconds	LV shutdown and tailoff begins
T + 3 seconds	S-IVB/CSM separation +X SM/RCS ON (4 jet)
T + 24 seconds	+X SM/RCS OFF, start orientation to SPS posigrade attitude
T + 125 seconds	posigrade attitude obtained (fig. 5-17) SPS engine ignition (SCS automatic)
Burn to achieve an h_p = 75 n. mi. and apply an additional 100 fps	SPS burn terminates

The initial mode IV capability is not dependent upon the amount of SPS propellant loaded for this mission, but is based on the SPS performance with the fixed burn attitude to achieve orbital velocity prior to premature entry. In addition, this capability is extremely sensitive to pitch errors during the maneuver (refs. 5 and 6). Therefore, the capability is defined for a ±5° pitch error bias during the burn. However, yaw errors up to ±5° have a negligible effect on the maneuver and are not included in this bias. These constraints limit the maximum ΔV to be used to less than 2400 fps for the nominal insertion altitude [fig. 5-18(a)].

A list of the pertinent trajectory parameters for mode IV maneuvers performed from the nominal trajectory are presented on table 5-V. The CSM IMU gimbal angles corresponding to the horizon monitor (31.7° window scribe mark) posigrade SPS burn attitude are presented on figure 5-17 for burns from the nominal trajectory. The mode IV ΔV requirements to achieve a 75-n. mi. perigee altitude are shown on figure 5-18 for deviations from the nominal flight-path angle and altitude. Additional mode IV information can be obtained from references 5 and 6.

5.4.2 <u>Apogee kick COI procedure</u>.- The mode IV COI maneuver is always performed 125 seconds after S-IVB cutoff. However, for some positive flight-path angles this maneuver can be delayed until apogee, which is called an apogee kick. The apogee kick capability begins once the S-IVB cutoff conditions would locate the apogee favorably for such a maneuver, or when apogee is greater than 5 minutes from cutoff is considered adequate. The apogee kick maneuver has the following significant advantages over the mode IV procedure: requires less ΔV, results in smaller apogees, gives the crew additional burn preparation time, and is less sensitive to burn execution errors.

The sequence of events simulated for an apogee kick maneuver are listed below:

T + 0 seconds	LV shutdown and begin tailoff
T + 3 seconds	S-IVB/CSM separation +X SM/RCS ON (4 jet)
T + 24 seconds	+X SM/RCS OFF, start orientation to SPS posigrade attitude
At apogee	posigrade attitude obtained SPS engine ignition (SCS automatic)
Burn to achieve an H_p = 75 n. mi. and apply an additional 100 fps	SPS burn terminates

The apogee kick ΔV's, times from S-IVB cutoff to apogee, and resulting apogees are shown on figure 5-19. These ΔV's are those required to achieve a 75-n. mi. perigee altitude, are smaller than the corresponding mode IV ΔV's shown on figure 5-18, and will be padded 100 fps, similar to the mode IV maneuvers.

TABLE 5-I.- DSKY PARAMETERS DURING LAUNCH

Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Altitude (n mi)	Altitude Rate (ft/sec)	SPLERROR (n mi)	Predicted Perigee (n mi)	Predicted Apogee (n mi)	Predicted Time of Free Fall to 300,000 Feet (min:sec)
00:00	1,342	0.0	0	-3,340.3*	-3,436.7	0.0	-59.59**
00:10	1,365	0.1	93	-3,340.3*	-3,436.7	0.1	-59.59**
00:20	1,366	0.4	211	-3,340.3*	-3,436.7	0.4	-59.59**
00:30	1,435	0.8	356	-3,340.3*	-3,436.4	1.1	-59:59**
00:40	1,567	1.5	529	-3,340.3*	-3,435.7	2.2	-59.59**
00:50	1,775	2.6	727	-3,340.2*	-3,434.6	3.9	-59:59**
01:00	2,060	3.9	949	-3,339.9*	-3,432.7	6.3	-59.59**
01:[illegible]	2,429	5.7	1,187	-3,339.4*	-3,429.9	9.3	-59.59**
01:20	2,872	7.9	1,450	-3,338.6*	-3,425.5	[illegible]	-59:59**
01:30	3,432	10.5	1,721	-3,337.1*	-3,418.5	18.2	-59:59**
01:40	4,103	13.5	1,991	-3,334.6*	-3,407.8	24.0	-59:59**
01:50	4,[illegible]	17.1	2,270	-3,330.9*	-3,392.3	30.8	-59:59**
02:00	5,[illegible]	21.0	2,562	-3,325.8*	-3,369.8	38.8	-59:59**
02:1[illegible]	6,733	25.3	2,824	-3,319.1*	-3,340.9	47.5	-59:59**
02:20	7,679	30.3	3,031	-2,998.5	-3,306.9	56.3	-3:24

*[illegible] = $R_{[illegible]}$ (distance from current position to target - apogee less than 300,000 feet)

**Time of free fall = [illegible] (-59:59) - apogee less than 300,000 feet

TABLE 5-I.- DSKY PARAMETERS DURING LAUNCH - Continued

Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Altitude (n mi)	Altitude Rate (ft/sec)	SPLERROR (n mi)	Predicted Perigee (n mi)	Predicted Apogee (n mi)	Predicted Time of Free Fall to 300,000 Feet (min:sec)
[illegible]:30	8,740	35.5	3,268	-2,975.0	-3,260.7	66.6	-3:25
[illegible]:40	8,937	40.3	3,117	-2,952.0	-3,247.6	69.4	-3:25
[illegible]:50	9,093	45.3	2,953	-2,929.5	-3,235.9	71.7	-3:26
[illegible]:00	9,262	50.5	2,795	-2,905.8	-3,223.4	73.9	-3:27
[illegible]:07.24[a]	9,392	53.8	2,685	-2,890.4	-3,214.0	75.5	-3:27
[illegible]:10	9,444	55.0	2,644	-2,884.2	-3,210.2	76.1	-3:27
[illegible]:20	9,637	59.3	2,505	-2,861.2	-3,196.4	78.4	-3:28
[illegible]:30	9,841	63.3	2,375	-2,837.2	-3,181.8	80.6	-3:29
[illegible]:40	10,057	67.1	2,245	-2,812.7	-3,166.1	82.7	-3:29
[illegible]:50	10,285	70.7	2,116	-2,787.6	-3,149.4	84.7	-3:30
[illegible]:00	10,525	74.1	1,988	-2,761.9	-3,131.4	86.6	-3:30
[illegible]:10	10,[illegible]7	77.3	1,862	-2,735.4	-3,112.2	88.3	-3:30
[illegible]:20	11,042	80.3	1,738	-2,708.2	-3,091.6	90.0	-3:29
[illegible]:30	11,319	83.0	1,616	-2,680.2	-3,069.5	91.5	-3:29
[illegible]:40	11,608	85.6	1,496	-2,651.2	-3,045.8	92.9	-3:28

[a]Launch escape tower jettison

TABLE 5-I.- DSKY PARAMETERS DURING LAUNCH - Continued

Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Altitude (n mi)	Altitude Rate (ft/sec)	SPLERROR (n mi)	Predicted Perigee (n mi)	Predicted Apogee (n mi)	Predicted Time of Free Fall to 300,000 Feet (min:sec)
04:50	11,910	88.0	1,380	-2,621.3	-3,020.3	94.3	-3:28
05:00	12,225	90.2	1,266	-2,590.3	-2,993.0	95.5	-3:27
05:10	12,553	92.2	1,156	-2,558.1	-2,963.5	96.7	-3:27
05:20	12,896	94.0	1,049	-2,524.6	-2,931.7	97.7	-3:26
05:30	13,249	95.7	947	-2,489.6	-2,897.4	98.7	-3.26
05:40	13,619	97.1	848	-2,453.1	-2,860.2	99.6	-3:26
05:50	14,003	98.5	754	-2,414.7	-2,820.0	100.4	-3.26
06:00	14,402	99.7	666	-2,374.2	-2,776.2	101.1	-3:26
06:10	14,817	100.7	582	-2,331.3	-2,728.5	101.8	-3:26
06:20	15,240	101.6	504	-2,285.7	-2,676.4	102.3	-3:27
06:30	15,697	102.4	433	-2,236.8	-2,619.4	102.9	-3:28
06:40	16,165	103.1	369	-2,184.2	-2,556.7	103.3	-3:30
06:50	16,651	103.6	312	-2,126.9	-2,487.5	103.7	-3:32
07:00	17,159	104.1	264	-2,064.2	-2,410.9	104.1	-3:35
07:10	17,680	104.5	221	-1,995.0	-2,325.6	104.4	-3:39
07:20	18,211	104.9	172	-1,923.7	-2,235.6	104.6	-3:43

TABLE 5-I.- DSKY PARAMETERS DURING LAUNCH - Continued

Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Altitude (n mi)	Altitude Rate (ft/sec)	SPLERROR (n mi)	Predicted Perigee (n mi)	Predicted Apogee (n mi)	Predicted Time of Free Fall to 300,000 Feet (min:sec)
7:30	18,646	105.1	110	-1,858.4	-2,152.0	104.8	-3:46
7:40	19,137	105.3	63	-1,782.3	-2,060.3	104.9	-3:49
7:50	19,625	105.4	31	-1,701.1	-1,959.1	104.9	-3:55
[illegible]	20,130	105.4	13	-1,606.2	-1,846.9	104.9	-4:03
[illegible]	20,656	105.5	18	-1,492.3	-1,722.2	105.0	-4:15
[illegible]	21,190	105.5	37	-1,368.9	-1,582.3	105.0	-4:31
[illegible]:30	21,765	105.6	68	-1,216.4	-1,424.0	105.1	-4:54
[illegible]:40	22,337	105.8	115	-1,016.4	-1,243.9	105.4	-5:26
[illegible]*	22,376	105.8	113	-1,008.0	-1,237.0	105.4	-5:27
[illegible]	22,454	106.0	68	-977.7	-1,212.4	105.4	-5:24
[illegible]	22,637	106.1	25	-910.9	-1,152.1	105.5	-5:28
[illegible]	22,825	106.1	-26	-843.6	-1,088.5	105.5	-5:30
[illegible]	23,017	106.0	-69	-771.1	-1,022.1	105.5	-5:34
[illegible]:30	23,211	105.9	-107	-690.0	-952.6	105.4	-5:39
[illegible]:40	23,408	105.7	-130	-598.5	-879.9	105.4	-5:46

*S-II/S-IVB Staging

TABLE 5-I.- DSKY PARAMETERS DURING LAUNCH - Concluded

Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Altitude (n mi)	Altitude Rate (ft/sec)	SPLERROR (n mi)	Predicted Perigee (n mi)	Predicted Apogee (n mi)	Predicted Time of Free Fall to 300,000 Feet (min:sec)
09:50	23,609	105.4	-162	-494.3	-803.8	105.3	-5:56
10:00	23,811	105.2	-179	-375.4	-724.2	105.2	-6:09
10:10	24,017	104.9	-188	-233.8	-640.5	105.0	-6:26
10:20	24,226	104.6	-189	-60.5	-552.8	104.8	-6:50
10:30	24,437	104.3	-182	158.5	-460.5	104.6	-7:22
10:40	24,650	104.0	-166	451.6	-363.5	104.4	-8:29
10:50	24,866	103.8	-142	872.4	-261.2	104.1	-9:22
11:00	25,084	103.6	-106	1,568.3	-153.8	103.6	-11:32
11:10	25,305	103.4	-62	3,091.1	-39.9	103.2	-16:36
11:20	25,528	103.4	-10	-1,970.0*	80.4	102.7	-59:59**
11:21.498***	25,[illegible]	103.4	-1	-1,964.2*	99.0	102.6	-59:59**
11:30	25,567	103.4	0	-1,931.3*	102.3	102.6	-59:59**
11:31.498****	25,5[illegible]	103.4	0	-1,925.5*	102.3	102.6	-59:59**

*SPLERROR = R_{TG-GO} (distance from current position to target - perigee greater than 300,000 feet)

**Time of free fall = POSMAX (-59:59) - perigee greater than 300,000 feet)

***Guidance cutoff

****Insertion

TABLE 5-II.- SUMMARY OF THE NOMINAL APOLLO C' MODE 1 (LEV) ABORT TRAJECTORIES

Abort time, min:sec	Abort altitude, ft	Abort apogee altitude, ft	Landing range, ft	Landing point: North geodetic latitude, deg:min:sec	Landing point: East longitude, deg:min:sec	G.e.t. to drogue deploy, min:sec	G.e.t. to main deploy, min:sec	G.e.t. to landing point, min:sec
(a) Mode 1a aborts								
00:00	424	4 648	5157	28:36:30	-80:35:27	00:16	00:28	01:31
00:05	525	5 139	5000	28:36:30	-80:35:18	00:21	00:33	02:37
00:10	955	5 959	4936	28:36:30	-80:35:15	00:26	00:38	02:34
00:15	1 469	7 156	4699	28:36:33	-80:35:22	00:31	00:43	03:22
00:20	2 368	8 625	4613	28:36:37	-80:35:24	00:36	00:48	04:16
00:25	3 596	10 316	5002	28:36:41	-80:35:20	00:41	00:53	05:16
00:30	5 197	12 346	5732	28:36:47	-80:35:13	00:46	00:58	06:24
00:35	7 619	13 415	6523	28:36:50	-80:34:59	00:52	01:04	07:02
00:37	8 384	15 979	7437	28:36:52	-80:34:[illegible]	00:53	[illegible]	[illegible]
00:40	9 502	17 718	8467	28:36:55	-80:34:44	00:56	01:37	06:35
00:42	10 685	18 988	9254	28:36:57	-80:34:35	00:58	01:44	06:39

TABLE 5-II.- SUMMARY OF THE NOMINAL APOLLO C' MODE I (LEV) ABORT TRAJECTORIES - Concluded

Abort time, min:sec	Abort altitude, ft	Abort apogee altitude, ft	Landing range, n. mi.	Landing point		G.e.t. to drogue deploy, min:sec	G.e.t. to main deploy, min:sec	G.e.t. to landing point, min:sec
				North geodetic latitude, deg:min:sec	East longitude, deg:min:sec			
(b) Mode Ib aborts								
00:43	11 260	20 281	1.45	28:36:55	-80:34:40	00:59	01:51	06:49
00:45	12 471	21 561	1.62	28:36:59	-80:34:29	01:01	01:55	06:56
00:50	15 853	25 379	2.10	28:37:07	-80:33:58	01:06	02:15	07:16
00:55	19 762	29 545	2.67	28:37:19	-80:33:22	01:11	02:39	07:36
01:00	24 228	34 530	3.41	28:37:33	-80:32:34	01:16	03:00	07:55
01:02	26 176	37 317	3.75	28:37:39	-80:31:11	01:18	03:11	08:08
01:03	27 183	38 585	4.04	28:38:02	-80:31:07	02:07	02:52	07:49
01:05	29 269	41 370	5.43	28:38:44	-80:30:20	02:15	02:59	07:57
01:10	34 903	50 772	7.52	28:38:51	-80:29:07	02:36	03:20	08:17
01:20	48 085	75 217	15.30	28:40:55	-80:19:58	03:21	04:05	09:02
01:30	63 964	114 341	33.96	28:46:49	-79:59:57	04:15	05:11	09:58
01:40	82 570	169 229	56.00	28:59:10	-79:26:06	05:13	05:57	10:54
01:48	99 437	216 473	114.00	29:10:05	-78:32:10	05:53	06:36	11:31
(c) Mode Ic aborts								
01:49	101 676	220 448	118	29:11:29	-78:27:46	05:55	06:19	11:36
02:00	128 162	292 256	185	29:30:27	-77:13:19	06:46	07:39	12:27
02:10	155 361	356 579	258	29:50:22	-75:53:22	07:26	08:10	13:08
02:20	184 749	416 382	339	30:10:22	-74:21:27	08:15	08:59	13:57
02:30	216 326	458 129	447	30:35:03	-72:33:41	08:55	09:42	14:39
02:40	248 598	503 462	461	30:41:55	[illegible]	09:07	09:51	14:49
02:50	279 973	514 554	491	30:47:23	-72:44:22	09:06	09:52	14:50
03:00	307 940	525 491	502	30:52:58	-72:16:25	09:14	09:58	14:55
03:07.4	328 409	533 507	520	30:57:16	-72:01:39	09:22	10:05	15:03

TABLE 5-III.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE II ABORTS [illegible]

(a) Entry parameters

Ground Elapsed Time of Abort (min:sec)	Inertial Velocity at Abort (ft/sec)	Maximum Entry Load Factor (g's)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight Path Angle at 400,000 Feet (deg)	Geodetic Latitude at Landing (deg North)	Longitude at Landing (deg West)	Range at Landing (n mi)
3:00.26*	9,391.36	9.67	9,157.60	-11.63	30.55	72.69	443.09
3:10	9,466.50	9.79	9,235.90	-11.66	30.57	72.37	449.28
3:20	9,647.10	10.15	9,510.73	-12.63	30.66	71.94	472.60
3:30	9,[illegible].92	10.53	9,[illegible].31	-13.06	30.75	71.48	496.36
3:40	10,[illegible].77	10.90	10,001.82	-13.47	30.83	71.02	520.93
3:50	10,2[illegible]	11.19	10,306.92	-13.77	30.92	70.54	546.12
4:00	10,505.[illegible]	11.53	10,603.00	-13.95	31.01	70.05	571.98
4:10	10,777.67	11.86	10,986.52	-14.06	31.09	69.56	598.57
4:20	11,0[illegible].07	12.00	11,295.95	-14.05	31.18	69.02	625.97
4:30	11,3[illegible].97	12.63	11,641.86	-14.00	31.27	68.48	654.26
4:40	11,[illegible].31	12.62	11,986.75	-13.90	31.35	67.92	683.46
4:50	11,960.27	12.93	12,265.27	-13.74	31.46	67.34	713.71
5:00	12,235.07	13.15	12,609.97	-13.55	31.53	66.74	745.98
5:10	12,558.96	13.29	12,951.92	-13.32	31.62	66.11	777.70
5:20	12,[illegible].27	13.56	13,300.59	-13.05	31.71	65.46	811.70
5:30	13,260.35	13.72	13,675.05	-12.76	31.79	64.77	847.23
5:40	13,[illegible].63	13.85	14,056.00	-12.46	31.88	64.05	884.48
5:50	14,[illegible].36	13.96	14,466.05	-12.10	31.97	63.29	923.67
6:00	14,[illegible].72	13.96	14,[illegible].63	-11.73	32.06	62.48	965.07
6:10	14,[illegible].77	13.93	15,262.77	-11.35	32.14	61.63	1,009.00
6:20	15,260.40	13.96	15,603.66	-10.95	32.23	60.71	1,055.66
6:30	15,607.62	13.90	16,130.71	-10.56	32.31	59.73	1,106.16
6:40	16,[illegible].76	13.78	16,602.76	-10.11	32.39	58.66	1,160.56
6:50	16,[illegible].40	13.50	17,[illegible]	-9.67	32.47	57.50	1,219.05

*Launch Escape Tower Jettison

TABLE 5-III.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE II ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(a) Entry parameters - Concluded

[illegible]	Inertial Velocity at Abort (ft/sec)	Maximum Entry Load Factor (g's)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight Path Angle at 400,000 Feet (deg)	Geodetic Latitude at Landing (deg North)	Longitude at Landing (deg West)	Range at Landing (n mi)
[illegible]	[illegible]	[illegible]	17,3[illegible].46	-9.21	32.33	56.21	1,2[illegible]5.12
[illegible]	[illegible]	[illegible]	18,1[illegible]	-8.76	32.39	5[illegible]	1,356.65
[illegible]	[illegible]	[illegible]	18,[illegible].63	-8.29	32.54	53.93	1,431.36
[illegible]	[illegible]	[illegible]	19,[illegible].34	-7.88	32.66	51.98	1,499.82
[illegible]	[illegible]	[illegible]	19,331.00	-7.47	32.66	50.46	1,576.96
[illegible]	[illegible]	[illegible]	20,012.08	-7.03	32.55	48.72	1,664.70
[illegible]	[illegible]	[illegible]	20,[illegible].21	-6.61	32.59	46.72	1,760.21
[illegible]	[illegible]	[illegible]	21,083.06	-6.10	32.48	44.33	1,887.46
[illegible]	[illegible]	9.39	21,330.98	-5.69	32.29	41.67	2,033.43
[illegible]	[illegible]	[illegible]	22,116.72	-5.21	31.95	37.97	2,212.99
[illegible]	[illegible]	7.33	22,[illegible].99	-4.69	31.35	33.47	2,443.89
[illegible]	[illegible]	7.38	22,713.06	-4.60	31.33	33.38	2,438.75
[illegible]	[illegible]	7.39	22,798.12	-4.61	31.22	32.69	2,486.93
[illegible]	[illegible]	7.36	22,993.85	-4.44	30.97	31.21	2,564.62
[illegible]	[illegible]	6.89	23,159.46	-4.27	30.70	29.70	2,644.20
[illegible]	[illegible]	6.40	23,367.00	-4.08	30.30	28.08	2,729.97
[illegible]	[illegible]	6.40	23,330.19	-3.89	30.01	26.30	2,825.26
[illegible]	[illegible]	5.70	23,731.36	-3.60	29.55	24.32	2,932.02
[illegible]	[illegible]	5.30	23,987.80	-3.40	28.99	22.10	3,053.12
[illegible]	[illegible]	4.89	24,125.08	-3.27	28.30	19.56	3,192.33

[illegible]

TABLE 5-III.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE II ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(b) Event times

[illegible]	[illegible]	Ground Elapsed Time at 400,000 Feet (min:sec)	Ground Elapsed Time at Landing (min:sec)	Ground Elapsed Time at S-band Blackout Entry (min:sec)	Ground Elapsed Time at S-band Blackout Exit (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)
[illegible][a]	[illegible]	[illegible]	[illegible]	----	----	9:44.75
[illegible]	[illegible]	[illegible]	[illegible]	----	----	9:47.73
[illegible]	[illegible]	[illegible]	[illegible]	----	----	9:58.00
[illegible]	[illegible]	[illegible]	[illegible]	----	----	10:10.32
[illegible]	[illegible]	[illegible]	[illegible]	----	----	10:21.70
[illegible]	[illegible]	[illegible]	[illegible]	----	----	10:33.25
[illegible]	[illegible]	[illegible]	[illegible]	----	----	10:44.70
[illegible]	[illegible]	[illegible]	[illegible]	----	----	10:56.40
[illegible]	[illegible]	[illegible]	[illegible]	----	----	11:08.15
[illegible]	[illegible]	[illegible]	[illegible]	----	----	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	----	----	11:30.17
[illegible]	[illegible]	[illegible]	[illegible]	----	----	11:44.30
[illegible]	[illegible]	[illegible]	[illegible]	----	----	11:57.00
[illegible]	[illegible]	[illegible]	[illegible]	----	----	12:08.97
[illegible]	[illegible]	[illegible]	[illegible]	----	----	12:23.10
[illegible]	[illegible]	[illegible]	[illegible]	9:40	9:46	12:36.70
[illegible]	[illegible]	[illegible]	[illegible]	9:48	9:53	12:50.02
[illegible]	[illegible]	[illegible]	[illegible]	9:56	10:05	13:05.34
[illegible]	[illegible]	[illegible]	[illegible]	10:05	[illegible]	13:20.52
[illegible]	[illegible]	[illegible]	[illegible]	10:14	10:29	13:36.35
[illegible]	[illegible]	[illegible]	[illegible]	10:24	10:41	13:52.96
[illegible]	[illegible]	[illegible]	[illegible]	10:35	10:53	14:10.40
[illegible]	[illegible]	[illegible]	[illegible]	10:46	11:06	14:29.13

[a] [illegible]

TABLE 5-III.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE II ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Concluded

(b) Event times - Concluded

[illegible]	[illegible]	[illegible]	Ground Elapsed Time at Landing (min:sec)	Ground Elapsed Time at S-band Blackout Entry (min:sec)	Ground Elapsed Time at S-band Blackout Exit (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)
[illegible]	[illegible]	[illegible]	20:47.23	10:50	11:20	14:40.13
[illegible]	[illegible]	[illegible]	[illegible]	11:10	11:35	15:10.73
[illegible]	[illegible]	[illegible]	[illegible]	11:24	11:51	15:33.99
[illegible]	[illegible]	[illegible]	[illegible]	11:37	12:07	15:57.62
[illegible]	[illegible]	[illegible]	[illegible]	11:49	12:21	16:18.95
[illegible]	[illegible]	[illegible]	[illegible]	12:03	12:37	16:42.70
[illegible]	[illegible]	[illegible]	[illegible]	12:19	12:56	17:08.37
[illegible]	[illegible]	[illegible]	[illegible]	12:37	13:17	17:32.71
[illegible]	[illegible]	[illegible]	[illegible]	12:50	13:43	18:15.45
[illegible]	[illegible]	[illegible]	24:13.45	13:26	14:16	18:37.60
[illegible]	[illegible]	[illegible]	[illegible]	13:50	14:52	19:40.57
[illegible]	[illegible]	[illegible]	[illegible]	14:42	15:43	20:33.28
[illegible]	[illegible]	[illegible]	[illegible]	14:43	15:44	20:54.62
[illegible][a]	[illegible]	[illegible]	[illegible]	14:50	15:52	21:08.39
[illegible]	[illegible]	[illegible]	[illegible]	15:06	16:00	21:25.72
[illegible]	[illegible]	[illegible]	[illegible]	15:17	16:26	21:47.17
[illegible]	[illegible]	[illegible]	[illegible]	15:31	16:42	22:10.19
[illegible]	[illegible]	[illegible]	[illegible]	15:47	17:02	22:35.60
[illegible]	[illegible]	[illegible]	[illegible]	16:05	17:23	23:04.15
[illegible]	[illegible]	[illegible]	[illegible]	16:26	17:40	23:30.31
[illegible]	[illegible]	[illegible]	30:11.18	16:50	18:16	24:13.18

[a][illegible]

TABLE 5-IV.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE III ABORTS FROM THE [illegible] LAUNCH TRAJECTORY

(a) High altitude

Ground Elapsed Time of Abort (hr:min:sec)	Inertial Velocity at Abort (ft/sec)	Ground Elapsed Time at SPS Ignition (min:sec)	SPS Burn Time (min:sec)	SPS ΔV (ft/sec)	Predicted Time of Free Fall From SPS Cutoff to 300,000 Feet (ft/sec)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight Path Angle at 400,000 Feet (deg)
[illegible]	[illegible]	12:05	0	0	4:04.68	24,1[illegible]	-3.2[illegible]
[illegible]	[illegible]	12:07	0	0	4:0[illegible]	24,[illegible]6[illegible].1	-3.2[illegible]
[illegible]	[illegible]	12:09	0	0	4:11.08	[illegible],205.2	-3.18
[illegible]	[illegible]	12:11	0	0	4:14.56	24,245.[illegible]	-3.13
[illegible]	[illegible]	12:13	0	0	4:18.22	24,285.7	-3.08
[illegible]	[illegible]	12:15	0	0	4:22.11	24,326.0	-3.04
[illegible]	[illegible]	12:17	0	0	4:26.26	24,366.4	-2.99
[illegible]	[illegible]	12:19	0	0	4:30.68	24,407.0	-2.94
[illegible]	[illegible]	12:21	0	0	4:35.[illegible]	24,[illegible]7.[illegible]	-2.[illegible]
[illegible]	[illegible]	12:23	0	0	4:[illegible]	24,[illegible]	-2.[illegible]
[illegible]	[illegible]	12:25	0	0	4:[illegible].5[illegible]	24,52[illegible].3	-2.7[illegible]
[illegible]	[illegible]	12:27	0	0	4:51.57	24,5[illegible]	-2.7[illegible]
[illegible]	[illegible]	12:29	0	0	4:56.98	24,608.0	-2.69
[illegible]	[illegible]	12:29	0:01.73	17.73	4:51.62	24,596.4	-2.72
[illegible]	[illegible]	12:31	0:06.11	63.75	4:44.90	24,611.1	-2.[illegible]
[illegible]	[illegible]	12:33	0:10.39	107.[illegible]5	4:38.19	2[illegible],624.0	-2.74

TABLE 5-IV.– TRAJECTORY CHARACTERISTICS FOLLOWING MODE III ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY -- Continued

(a) High altitude – Continued

Ground Elapsed Time of Abort (min:sec)	Inertial Velocity at Abort (ft/sec)	Ground Elapsed Time at SPS Ignition (min:sec)	SPS Burn Time (min:sec)	SPS ΔV (ft/sec)	Predicted Time of Free Fall From SPS Cutoff to 300,000 Feet (ft/sec)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight Path Angle at 400,000 Feet (deg)
[illegible]	[illegible]	[illegible]	0:14.57	152.59	4:31.72	24,636.5	-2.76
[illegible]	[illegible]	[illegible]	0:18.94	198.86	4:25.14	24,648.5	-2.78
[illegible]	[illegible]	[illegible]	0:23.40	246.24	4:18.58	24,660.0	-2.80
[illegible]	[illegible]	[illegible]	0:27.96	294.97	4:11.99	24,671.0	-2.82
[illegible]	[illegible]	[illegible]	0:32.59	344.62	4:05.50	24,681.9	-2.85
[illegible]	[illegible]	[illegible]	0:37.32	395.69	3:58.99	24,692.3	-2.88
[illegible]	[illegible]	[illegible]	0:42.19	448.40	3:52.37	24,702.0	-2.91
[illegible]	[illegible]	[illegible]	0:45.13	502.22	3:45.84	24,711.4	-2.94
[illegible]	[illegible]	[illegible]	0:52.18	557.58	3:39.26	24,720.3	-2.98
[illegible]	[illegible]	[illegible]	0:57.37	614.82	3:32.64	24,728.4	-3.02
[illegible]	[illegible]	[illegible]	1:02.66	673.35	3:26.13	24,736.1	-3.06
[illegible]	[illegible]	[illegible]	1:08.16	734.68	3:19.51	24,742.6	-3.11
[illegible]	[illegible]	[illegible]	1:13.83	798.33	3:12.82	24,748.2	-3.16
[illegible]	[illegible]	[illegible]	1:19.60	863.43	3:06.22	24,753.4	-3.22
[illegible]	[illegible]	[illegible]	1:25.34	930.91	2:59.51	24,757.9	-3.28
[illegible]	[illegible]	[illegible]	1:31.56	1,000.00	2:52.90	24,762.2	-3.34

TABLE 5-IV.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE III ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(a) High altitude - Concluded

Ground Elapsed Time of Abort (min:sec)	Inertial Velocity at Abort (ft/sec)	Ground Elapsed Time at SPS Ignition (min:sec)	SPS Burn Time (min:sec)	SPS ΔV (ft/sec)	Predicted Time of Free Fall From SPS Cutoff to 300,000 Feet (ft/sec)	Inertial Velocity at 400,000 Feet (ft/sec)	Inertial Flight Path Angle at 400,000 Feet (deg)
[illegible]	[illegible]	13:07	1:37.94	1,073.29	2:45.95	24,764.8	-3.41
[illegible]	[illegible]	13:09	1:44.43	1,140.64	2:39.08	24,767.0	-3.49
[illegible]	[illegible]	13:11	1:51.16	1,227.25	2:32.09	24,768.2	-3.57
[illegible]	[illegible]	13:13	1:58.04	1,308.37	2:25.11	24,768.7	-3.65
[illegible]	[illegible]	13:15	2:05.16	1,392.99	2:18.04	24,768.2	-3.75
[illegible]	[illegible]	13:17	2:12.59	1,482.00	2:10.76	24,766.3	-3.85
[illegible]	[illegible]	13:19	2:20.28	1,575.85	2:03.39	24,763.4	-3.96
[illegible]	[illegible]	13:21	2:28.21	1,671.84	1:56.00	24,759.7	-4.08
[illegible]	[illegible]	13:23	2:36.66	1,776.06	1:48.13	24,753.6	-4.21
[illegible]	[illegible]	13:25	2:46.49	1,886.02	1:40.09	24,746.2	-4.35
[illegible][a]	[illegible]	13:26.40	2:52.14	1,969.65	1:34.27	24,740.8	-4.46
[illegible]	[illegible]	13:27	2:52.82	1,987.35	1:33.39	24,738.1	-4.48
[illegible]	[illegible]	13:29	2:54.73	2,002.53	1:30.55	24,727.8	-4.53
[illegible]	[illegible]	13:31	2:56.36	2,025.76	1:27.83	24,717.6	-4.58
[illegible]	[illegible]	13:33	2:58.47	2,050.80	1:25.06	24,707.0	-4.63
[illegible]	[illegible]	13:35	3:00.21	2,072.25	1:22.46	24,697.3	-4.67
[illegible][aa]	[illegible]	13:36.40	3:01.76	2,091.78	1:20.26	24,688.8	-4.71

[a] Guidance cutoff signal

[aa] Insertion

TABLE 5-IV.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE III ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(b) Low altitude

Ground Elapsed Time of Abort (min:sec)	Ground Elapsed Time at S-Band Blackout Entry (min:sec)	Ground Elapsed Time at S-Band Blackout Exit (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)	Geodetic Latitude At Landing (Deg North)	Longitude At Landing (Deg West)	Maximum Load Factor (g's)
[illegible]	[illegible]	18:12	[illegible]	28.47	24.15	6.90
[illegible]	[illegible]	[illegible]	[illegible]	28.33	23.65	6.78
[illegible]	[illegible]	[illegible]	[illegible]	28.19	23.13	6.67
[illegible]	[illegible]	[illegible]	22:22.97	28.05	22.59	6.55
[illegible]	[illegible]	[illegible]	22:31.05	27.89	22.04	6.43
[illegible]	[illegible]	[illegible]	22:39.42	27.73	21.46	6.31
[illegible]	[illegible]	[illegible]	22:48.13	27.56	20.87	6.18
[illegible]	[illegible]	[illegible]	22:57.20	27.37	20.25	6.05
[illegible]	[illegible]	[illegible]	23:06.66	27.18	19.61	5.92
[illegible]	[illegible]	[illegible]	23:17.25	28.11	18.47	5.80
[illegible]	[illegible]	[illegible]	23:26.90	26.75	18.24	5.67
[illegible]	[illegible]	[illegible]	23:37.69	26.52	17.52	5.53
[illegible]	[illegible]	[illegible]	23:47.99	26.29	16.83	5.42
[illegible]	[illegible]	[illegible]	23:43.06	26.40	17.15	5.47
[illegible]	[illegible]	[illegible]	23:42.77	26.40	17.14	5.47
[illegible]	[illegible]	[illegible]	23:42.33	26.40	17.15	5.47

TABLE 5-IV.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE III ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(b) Low altitude - Continued

Ground Elapsed Time of Abort (hr:min:sec)	Ground Elapsed Time at S-Band Blackout Entry (min:sec)	Ground Elapsed Time at S-Band Blackout Exit (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (hr:min:sec)	Geodetic Latitude at Landing (Deg North)	Longitude at Landing (Deg West)	Maximum Load Factor (g's)
[illegible]	[illegible]	10:43	23:42.82	26.40	17.14	5.48
[illegible]	[illegible]	10:42	23:41.59	26.40	17.14	5.49
[illegible]	[illegible]	10:42	23:41.17	26.40	17.14	5.51
[illegible]	[illegible]	10:41	23:40.69	26.40	17.15	5.53
[illegible]	[illegible]	10:41	23:40.32	26.40	17.14	5.55
[illegible]	[illegible]	10:41	23:39.90	26.40	17.14	5.59
[illegible]	[illegible]	10:40	23:39.39	26.41	17.14	5.62
[illegible]	[illegible]	10:40	23:38.91	26.41	17.14	5.66
[illegible]	[illegible]	[illegible]	23:38.38	26.41	17.14	5.71
[illegible]	[illegible]	10:39	23:37.81	26.42	17.14	5.77
[illegible]	[illegible]	10:38	23:37.33	26.42	17.14	5.83
[illegible]	[illegible]	10:39	23:36.76	26.42	17.13	5.90
[illegible]	[illegible]	10:39	23:36.12	26.43	17.14	5.98
[illegible]	[illegible]	10:38	23:35.55	26.43	17.13	6.07
[illegible]	[illegible]	10:38	23:34.90	26.44	17.13	6.17
[illegible]	[illegible]	10:38	23:34.34	26.44	17.12	6.27

TABLE 5-IV.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE III ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Concluded

(b) Low altitude - Concluded

Ground Elapsed Time of Abort Initiation	Ground Elapsed Time at 0.05g Blackout Entry (min:sec)	Ground Elapsed Time at 0.05g Blackout Exit (min:sec)	Ground Elapsed Time at Drogue Chute Deployment (min:sec)	Geodetic Latitude at Landing (Deg North)	Longitude at Landing (Deg West)	Maximum Load Factor (g's)
[illegible]	[illegible]	10:30	23:33.49	26.45	17.12	6.40
[illegible]	[illegible]	10:30	23:32.74	26.46	17.12	6.53
[illegible]	[illegible]	10:30	23:31.89	26.47	17.12	6.68
[illegible]	[illegible]	10:30	23:31.08	26.47	17.12	6.84
[illegible]	[illegible]	10:30	23:30.22	26.48	17.11	7.02
[illegible]	[illegible]	10:30	23:29.22	26.49	17.11	7.22
[illegible]	[illegible]	10:30	23:28.20	26.50	17.10	7.43
[illegible]	[illegible]	10:30	23:27.23	26.51	17.09	7.67
[illegible]	[illegible]	10:30	23:25.93	26.53	17.10	7.94
[illegible]	[illegible]	10:30	23:24.50	26.55	17.10	8.24
[illegible] [a]	[illegible]	10:39	23:23.81	26.55	17.08	8.47
[illegible]	[illegible]	10:39	23:23.65	26.56	17.08	8.50
[illegible]	[illegible]	10:39	23:23.22	26.56	17.08	8.62
[illegible]	[illegible]	10:39	23:22.87	26.57	17.08	8.73
[illegible]	[illegible]	10:39	23:22.47	26.58	17.09	8.84
[illegible]	[illegible]	10:40	23:22.32	26.58	17.07	8.96
[illegible] [aa]	[illegible]	10:40	23:21.96	26.58	17.08	9.04

[a] Guidance cutoff signal

[aa] Insertion

TABLE 5-[illegible].- TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY

(a) Without ΔV pad

At Abort Initiation		At SPS Ignition				After Nominal SPS Burn			
[illegible]	Inertial Velocity [illegible]	Inner Gimbal Angle [illegible]	Middle Gimbal Angle [illegible]	Outer Gimbal Angle [illegible]	Ground Elapsed Time (min:sec)	SPS Burn Duration (min:sec)	SPS Sensed Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11:55	3:12.30	2,227.6	334.77	150.13
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11:57	3:08.12	2,173.7	332.30	147.30
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11:5[illegible]	3:0[illegible].99	2,120.6	[illegible]29.92	144.86
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:0[illegible]	2:57.[illegible]	2,0[illegible].1	327.50	142.63
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:0[illegible]	2:55.78	2,015.9	325.28	140.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:05	2:51.[illegible]	1,964.0	323.[illegible]	138.67
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:0[illegible]	2:47.50	1,912.2	320.73	136.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:0[illegible]	2:43.[illegible]	1,[illegible].8	318.[illegible]	135.21
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:11	2:39.37	1,[illegible].6	316.26	133.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:13	2:35.27	1,750.8	314.[illegible]	132.26
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:15	2:31.17	1,708.2	311.91	130.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:17	2:27.05	1,657.6	309.71	129.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:19	2:22.92	1,607.1	307.[illegible]	128.31
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:21	2:18.77	1,556.7	305.22	127.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:23	2:14.60	1,506.2	302.92	125.75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:25	2:10.41	1,455.8	300.50	124.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:27	2:06.21	1,405.5	298.25	123.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:29	2:02.36	1,350.9	296.20	122.50
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:31	1:57.79	1,305.6	293.56	121.27
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:33	1:53.57	1,255.6	291.21	120.27

TABLE [illegible] TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE [illegible] LAUNCH TRAJECTORY - Continued

(a) Without ΔV pad - Continued

[illegible]	[illegible]	At SPS Ignition				After Nominal SPS Burn			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Elapsed Time (min:sec)	SPS Burn Duration (min:sec)	SPS Induced Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)
[illegible]	[illegible]	[illegible]	[illegible]	100.47	12:35	1:40.3	1,205.6	288.66	119.15
[illegible]	[illegible]	[illegible]	[illegible]	100.47	12:37	1:45.0	1,195.7	286.06	118.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	100.47	12:38	1:40.7	1,185.9	283.44	117.05
[illegible]	[illegible]	[illegible]	0.05	100.47	12:41	1:36.6	1,[illegible].1	[illegible].70	116.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:43	1:32.1	1,[illegible].2	277.90	115.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:46	1:27.7	956.6	275.09	114.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:47	1:23.6	[illegible]	272.10	113.13
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:49	1:19.0	857.2	269.14	112.25
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:51	1:14.6	807.7	266.12	111.40
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:53	1:10.2	750.3	262.97	110.56
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:55	1:05.9	700.0	259.66	109.73
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:57	1:01.[illegible]	650.7	256.01	108.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	100.30	12:59	0:57.0	610.5	252.18	107.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	100.30	13:01	0:52.5	561.6	248.29	107.29
[illegible]	[illegible]	[illegible]	[illegible]	100.30	13:03	0:48.1	512.6	244.34	106.40
[illegible]	[illegible]	[illegible]	[illegible]	100.30	13:05	0:43.6	463.5	240.29	105.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	100.32	13:07	0:39.1	414.6	236.11	105.22
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13:09	0:34.6	365.8	231.82	104.47
[illegible]	[illegible]	[illegible]	[illegible]	100.31	13:11	0:30.0	317.1	227.42	104.10
[illegible]	[illegible]	[illegible]	[illegible]	100.31	13:13	0:25.5	268.7	222.93	103.77
[illegible]	[illegible]	[illegible]	[illegible]	100.28	13:15	0:21.0	220.6	218.33	103.48
[illegible]	[illegible]	[illegible]	[illegible]	100.28	13:17	0:16.6	172.2	213.63	103.16

TABLE 5-V.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(a) Without ΔV grd - Concluded

[illegible]		[illegible]				After [illegible] SPS Burn			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Elapsed Time (min:sec)	SPS Burn Duration (min:sec)	Sensed Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)
[illegible]	[illegible]	[illegible]	0.00	[illegible]	13:19	0:11.9	126.1	202.06	107.96
[illegible]	[illegible]	[illegible]	0.00	[illegible]	13:21	0:07.3	76.2	203.96	102.81
[illegible]	[illegible]	[illegible]	0.00	[illegible]	13:23	0:02.7	28.6	198.99	102.76
[illegible]	[illegible]	[illegible]	0.00	[illegible]	13:25	0:00	0.0	196.1[illegible]	102.72
[illegible] [illegible]	[illegible]	[illegible]	0.79	[illegible]	13:26.5	0:00	0.0	7.62	103.50
[illegible] [illegible]	[illegible]	[illegible]	0.79	[illegible]	13:26.7	0:00	0.0	12.06	104.60
[illegible]	[illegible]	[illegible]	0.79	[illegible]	13:27	0:00	0.0	10.99	106.26
[illegible]	[illegible]	[illegible]	0.79	[illegible]	13:29	0:00	0.0	11.50	106.52
[illegible]	[illegible]	[illegible]	0.79	[illegible]	13:31	0:00	0.0	11.62	106.53
[illegible]	[illegible]	[illegible]	0.79	[illegible]	13:33	0:00	0.0	11.65	106.55
[illegible]	[illegible]	[illegible]	0.79	[illegible]	13:35	0:00	0.0	11.68	106.57
[illegible] [illegible]	[illegible]	[illegible]	0.79	[illegible]	13:36.5	0:00	0.0	11.71	106.59

[illegible]

[illegible]

2

TABLE 5-V.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(b) With 10 -fps pad

At Abort Initiation		After Burn Pad of 100 ft/sec				
Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Total SPS Burn Duration (min:sec)	Total SPS Sensed Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)	Predicted Perigee Altitude (n mi)
9:50	23,608.6	3:19.97	2,327.6	352.11	194.47	77.87
9:52	23,648.9	3:15.84	2,273.7	350.96	191.32	78.27
9:54	23,689.5	3:11.75	2,220.6	349.88	188.56	78.66
9:56	23,730.0	3:07.68	2,168.1	348.84	186.03	79.06
9:58	23,770.7	3:03.62	2,115.9	347.84	183.68	79.46
10:00	23,811.5	2:59.57	2,064.0	346.87	181.46	79.87
10:02	23,852.5	2:55.50	2,012.2	345.93	179.35	80.29
10:04	23,893.6	2:51.43	1,960.8	345.03	177.36	80.70
10:06	23,934.7	2:47.37	1,909.6	344.15	175.51	81.12
10:08	23,976.0	2:43.31	1,858.8	343.31	173.79	81.54
10:10	24,017.0	2:39.25	1,808.2	342.50	172.13	81.96
10:12	24,058.8	2:35.17	1,757.6	341.71	170.48	82.40

TABLE 5-V.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(b) With 100-fps pad - Continued

At Abort Initiation		After Burn Pad of 100 ft/sec				
Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Total SPS Burn Duration (min:sec)	Total SPS Sensed Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)	Predicted Perigee Altitude (n mi)
10:14	24,100.3	2:31.08	1,707.1	340.94	168.85	82.84
10:16	24,141.9	2:26.98	1,656.7	340.20	167.23	83.29
10:18	24,183.7	2:22.84	1,606.2	339.48	165.63	83.75
10:20	24,225.7	2:18.69	1,555.8	338.78	164.05	84.22
10:22	24,267.8	2:14.54	1,505.5	338.12	162.52	84.70
10:24	24,309.8	2:10.75	1,459.9	337.54	161.37	85.11
10:26	24,352.0	2:06.20	1,405.4	336.87	159.62	85.67
10:28	24,394.3	2:02.02	1,355.6	336.29	158.24	86.16
10:30	24,436.7	1:57.80	1,305.6	335.75	156.70	86.69
10:32	24,479.1	1:53.58	1,255.7	335.24	155.22	87.22
10:34	24,521.6	1:49.33	1,205.9	334.78	153.74	87.77
10:36	24,564.3	1:45.07	1,156.1	334.36	152.27	88.32
10:38	24,607.1	1:40.79	1,106.2	333.99	150.81	88.90
10:40	24,650.1	1:36.48	1,056.4	333.67	149.36	89.49
10:42	24,693.2	1:32.16	1,006.7	333.42	147.93	90.09

TABLE 5-V.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Continued

(b) With 100-fps pad - Continued

At Abort Initiation		After Burn Pad of 100 ft/sec				
Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Total SPS Burn Duration (min:sec)	Total SPS Sensed Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)	Predicted Perigee Altitude (n mi)
10:44	24,736.3	1:27.84	957.2	333.22	146.56	90.69
10:46	24,779.5	1:23.50	907.7	333.10	145.21	91.30
10:48	24,822.8	1:19.15	858.3	333.07	143.84	91.94
10:50	24,866.1	1:14.78	809.0	333.15	142.46	92.59
10:52	24,909.5	1:10.40	759.7	333.41	140.98	93.30
10:54	24,952.8	1:06.00	710.5	333.84	139.50	94.03
10:56	24,996.3	1:01.58	661.4	334.43	138.09	94.76
10:58	25,039.9	0:57.16	612.4	335.20	136.76	95.49
11:00	25,083.7	0:52.72	563.5	336.19	135.47	96.23
11:02	25,127.7	0:48.26	514.6	337.44	134.24	96.97
11:04	25,171.8	0:43.79	465.8	338.98	133.07	97.70
11:06	25,216.0	0:39.30	417.1	340.87	131.97	98.43
11:08	25,260.2	0:34.82	368.7	343.13	130.96	99.13
11:10	25,304.5	0:30.30	320.4	345.82	130.05	99.81
11:12	25,348.9	0:25.80	272.2	348.98	129.24	100.45
11:14	25,393.4	0:21.30	224.1	352.63	128.57	101.03

TABLE 5-V.- TRAJECTORY CHARACTERISTICS FOLLOWING MODE IV ABORTS FROM THE NOMINAL LAUNCH TRAJECTORY - Concluded

(b) With 100-fps pad - Concluded

At Abort Initiation		After Burn Pad of 100 ft/sec				
Ground Elapsed Time (min:sec)	Inertial Velocity (ft/sec)	Total SPS Burn Duration (min:sec)	Total SPS Sensed Velocity Change (ft/sec)	True Anomaly (deg)	Predicted Apogee Altitude (n mi)	Predicted Perigee Altitude (n mi)
11:16	25,438.0	0:16.8	176.2	356.79	128.04	101.54
11:18	25,482.7	0:12.3	128.4	1.43	127.68	101.97
11:20	25,527.5	0:09.6	100.0	7.79	137.15	102.21
11:21.5	25,561.0	0:09.6	100.0	10.78	156.52	102.20
11:21.7	25,565.1	0:09.6	100.0	10.82	156.75	102.20
11:22	25,566.1	0:09.6	100.0	10.86	157.23	102.20
11:24	25,566.8	0:09.6	100.0	10.88	157.48	102.20
11:26	25,566.9	0:09.6	100.0	10.88	157.50	102.20
11:28	25,566.9	0:09.6	100.0	10.88	157.52	102.20
11:30	25,566.9	0:09.6	100.0	10.89	157.54	102.20
11:31.5	25,567.0	0:09.6	100.0	10.89	157.56	102.20

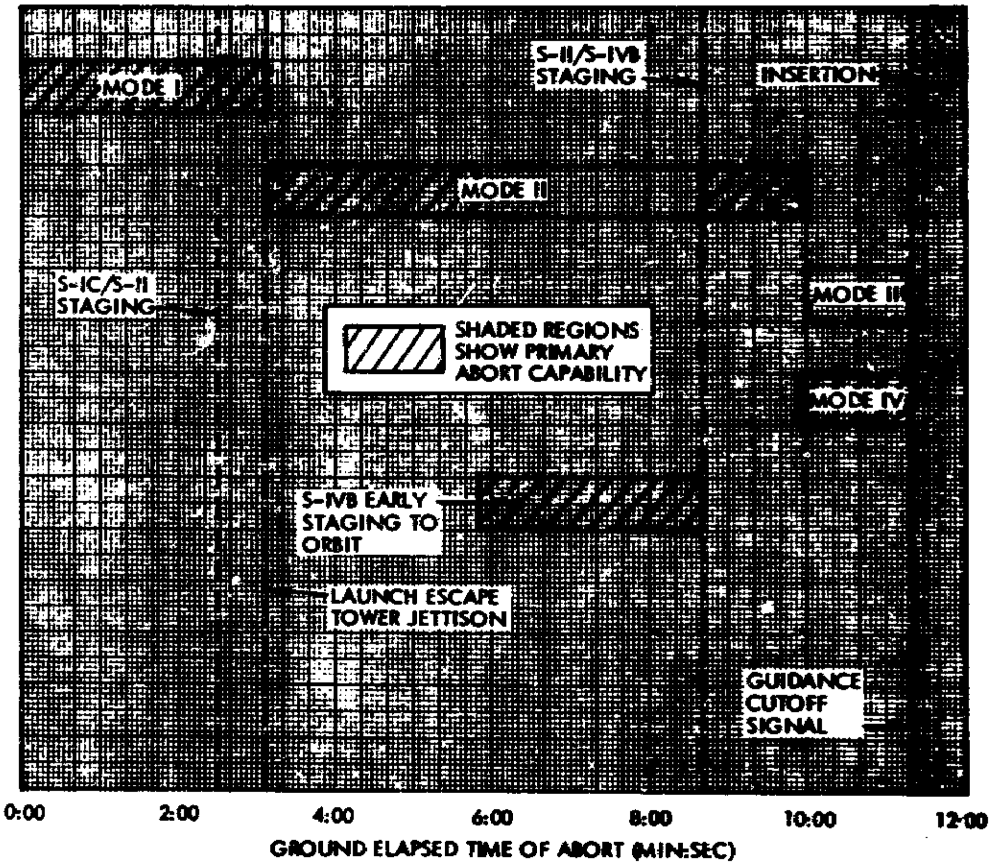


Figure 5-1.- Nominal launch abort mode timeline.

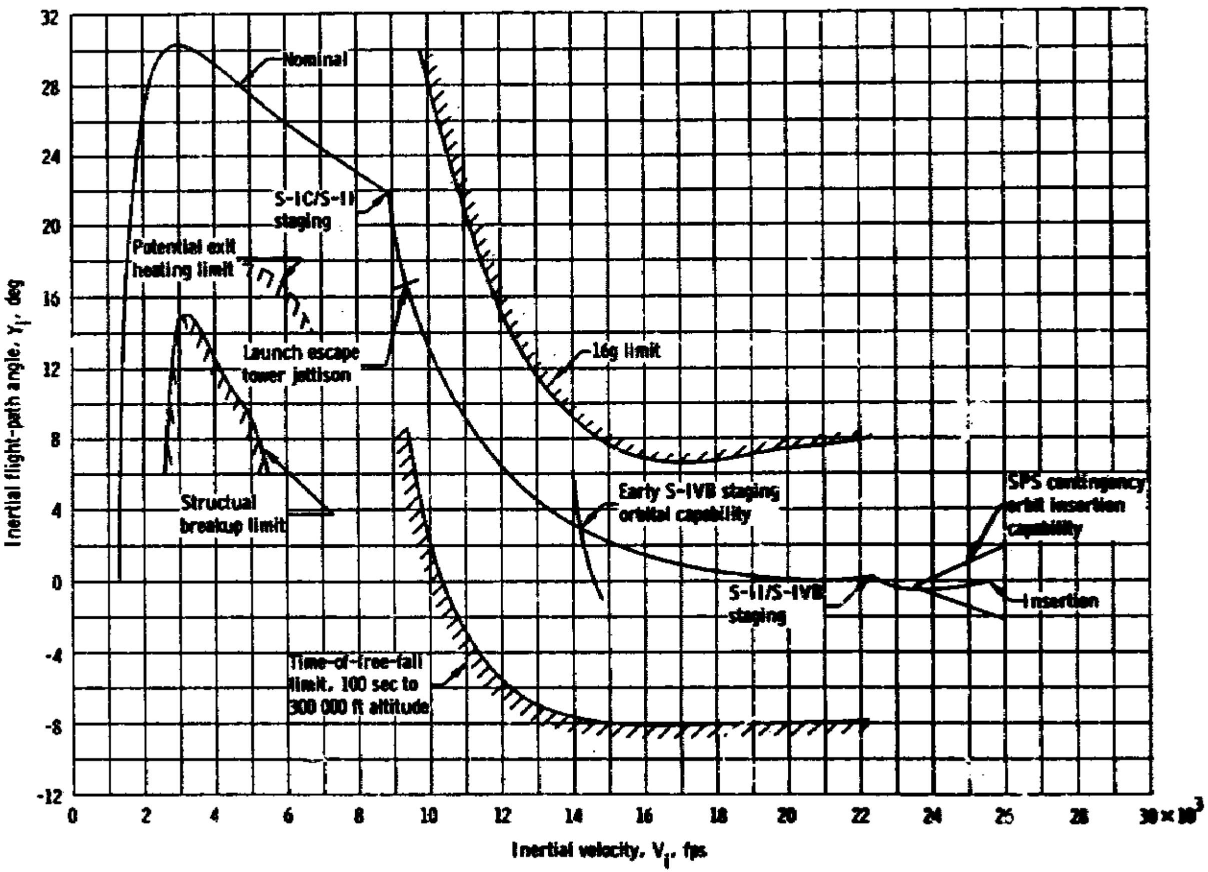


Figure 5-2. - Launch abort trajectory limits.

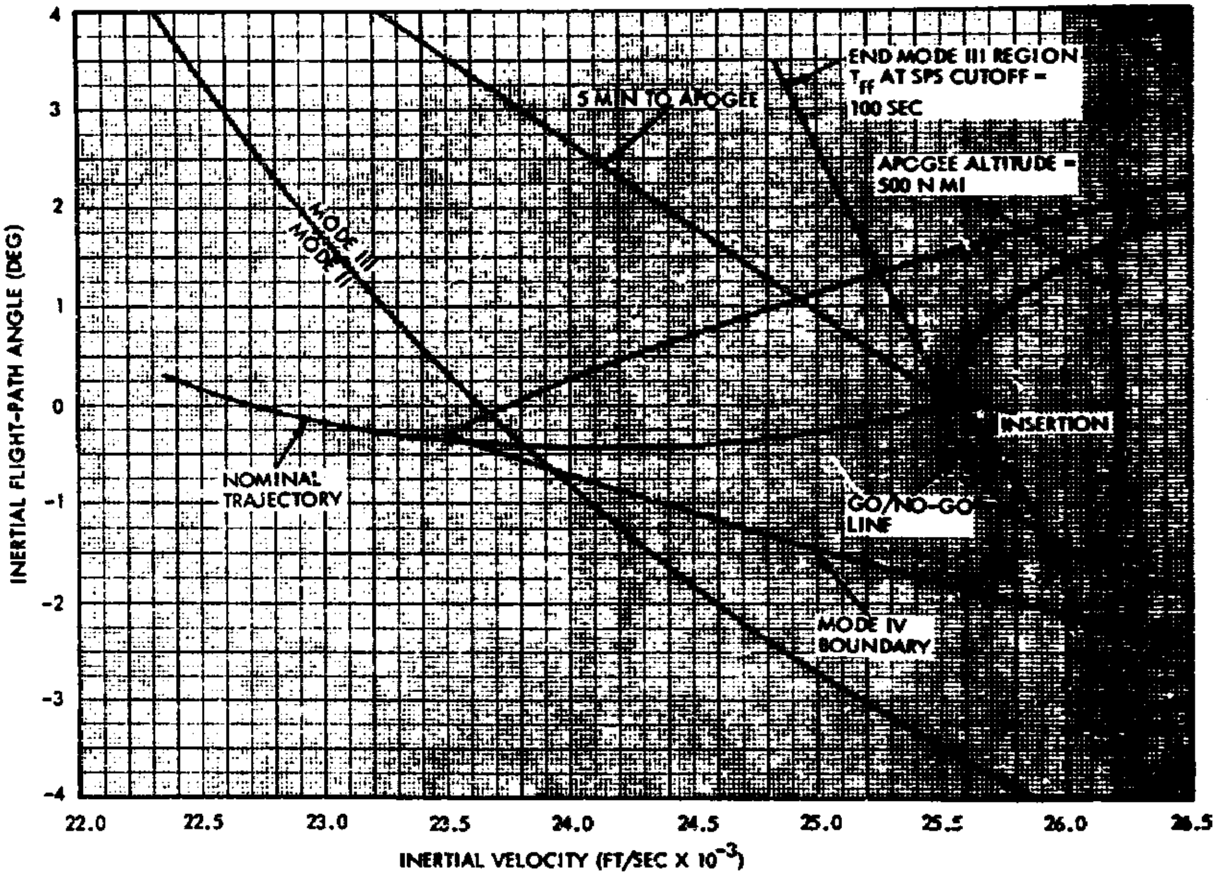


Figure 5-3.- Near-insertion abort mode overlap.

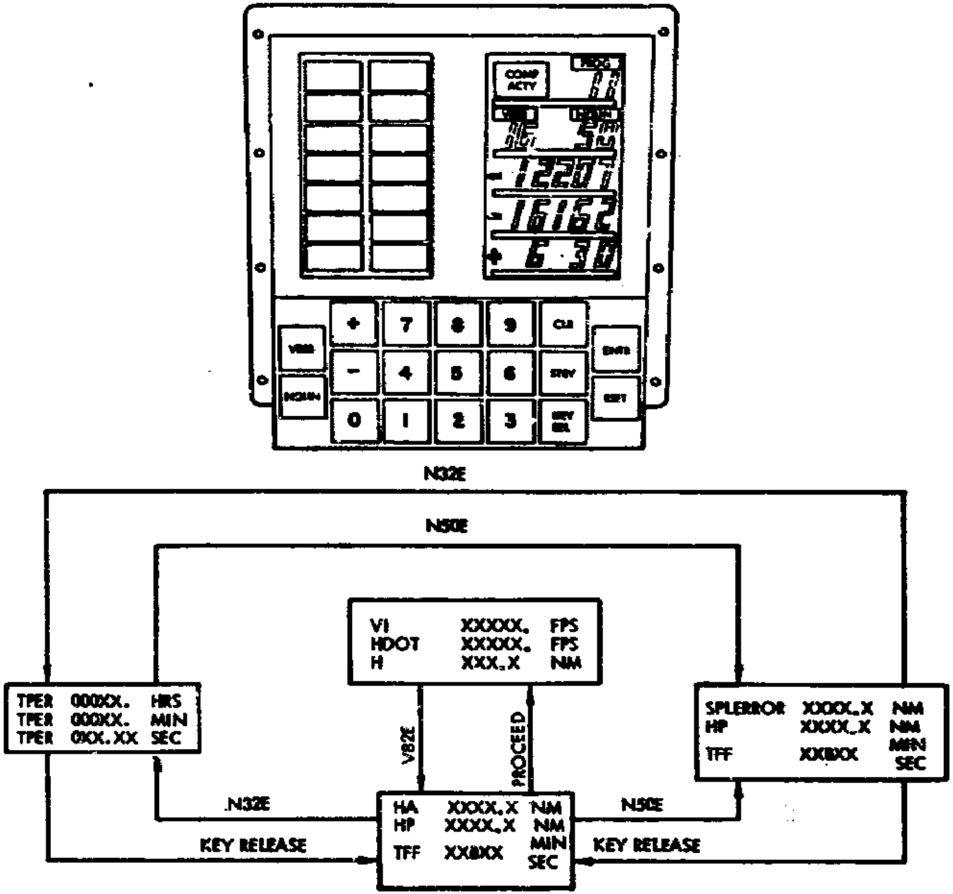


Figure 5-4.- AGC display keyboard panel and display parameters.

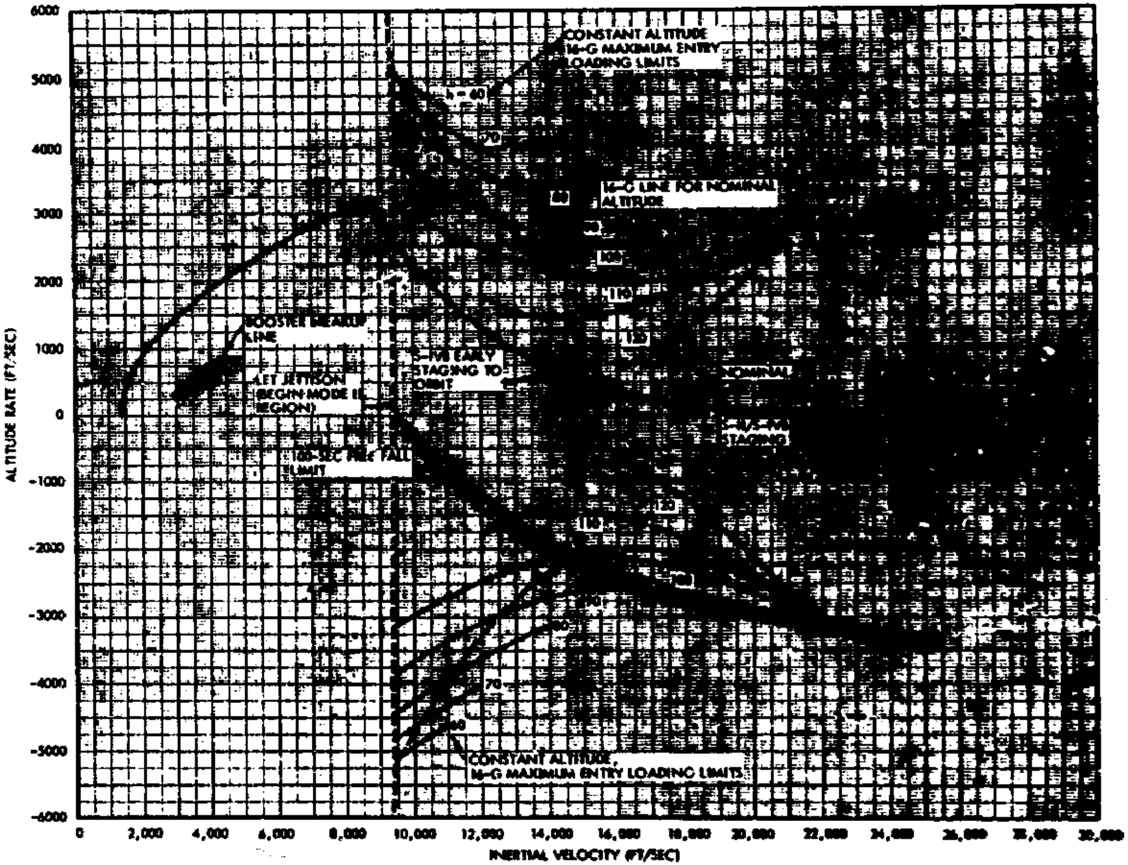


Figure 5-5.- No-voice crew chart 1 for the launch phase.

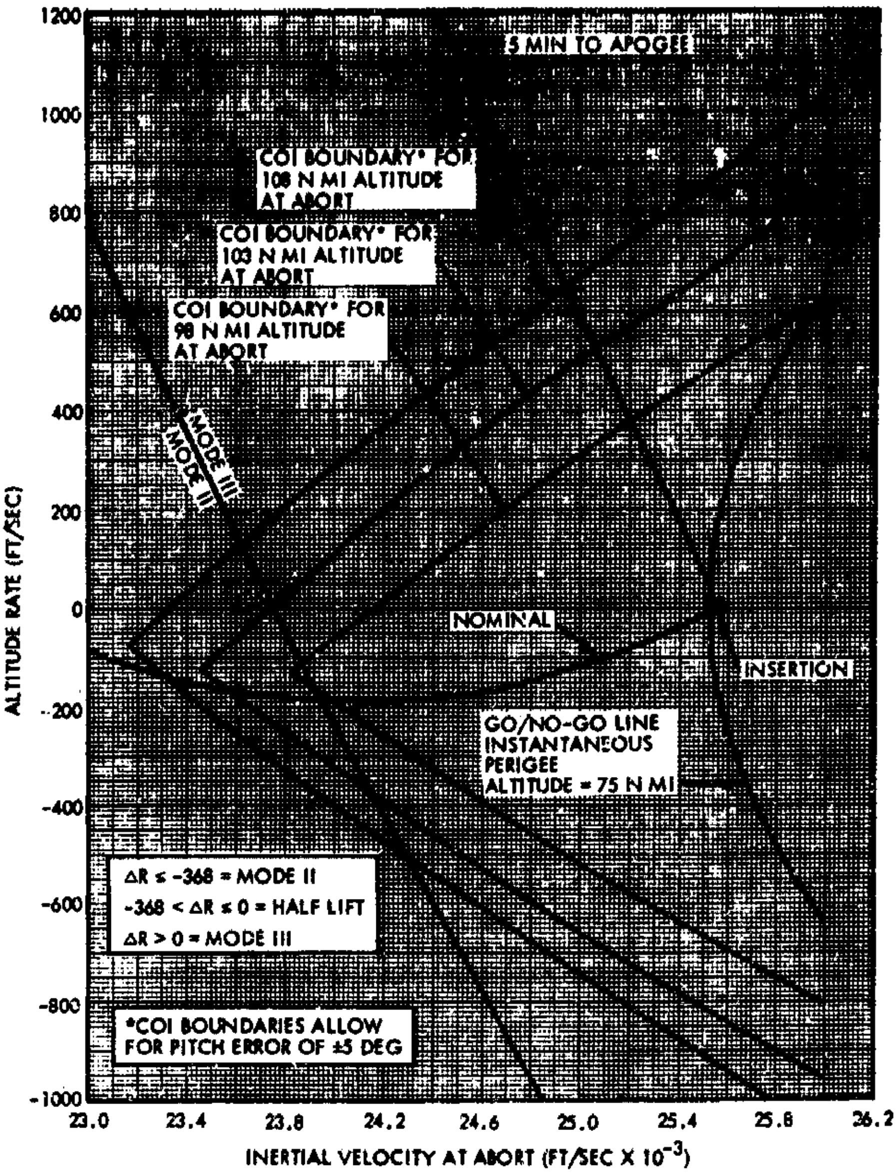


Figure 5-6.- No-voice crew chart 2 for the launch phase.

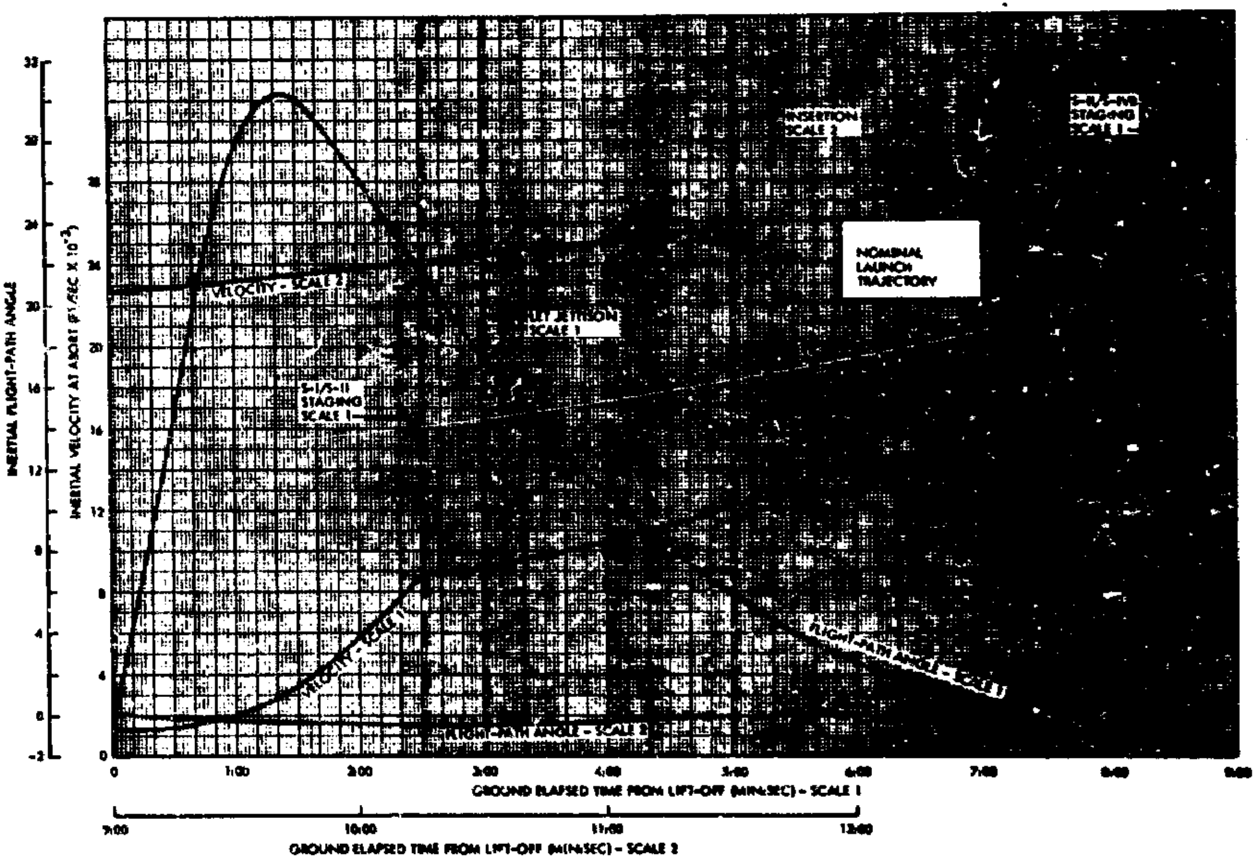


Figure 5-7.- Inertial velocity and inertial flight-path angle along the nominal ascent trajectory.

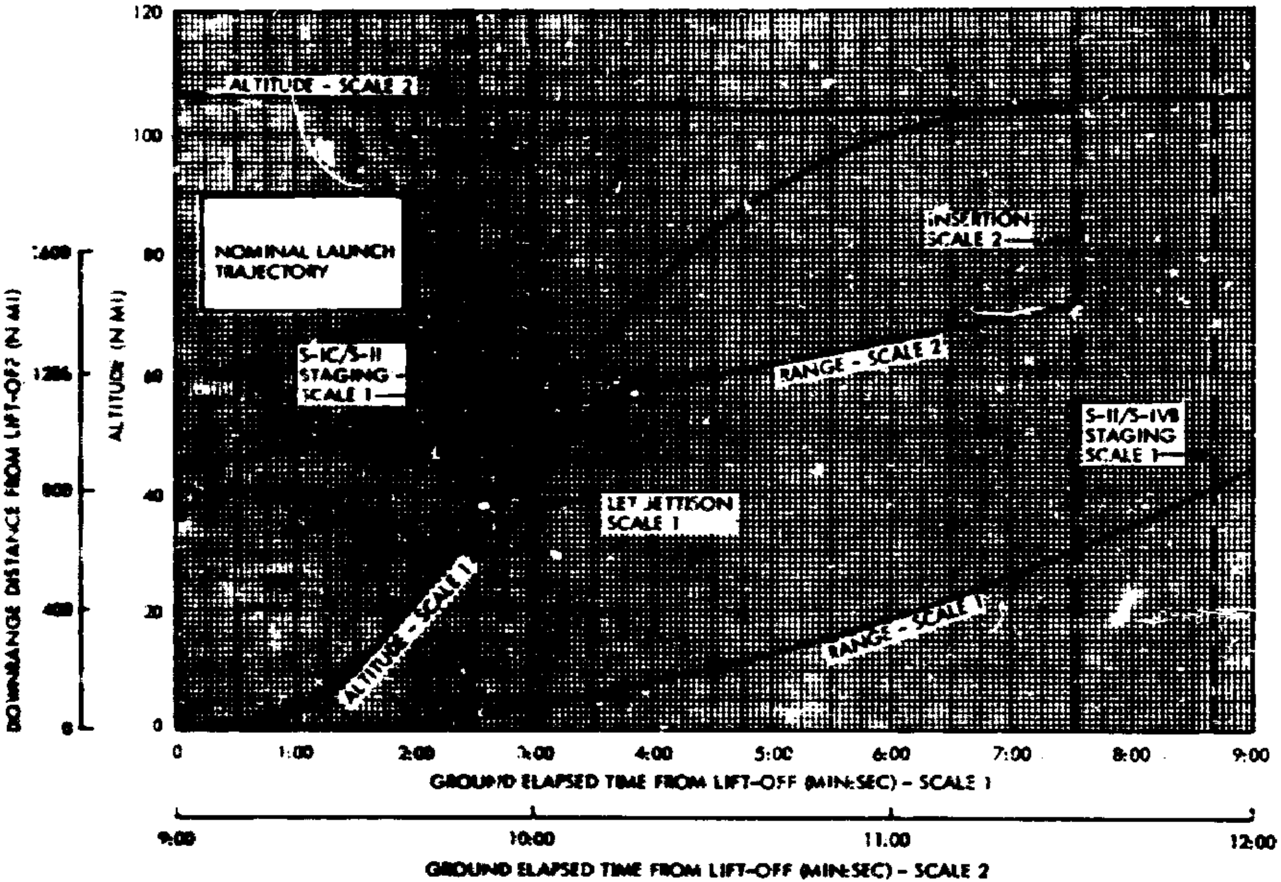


Figure 5-8.- Downrange distance and altitude along the nominal launch trajectory.

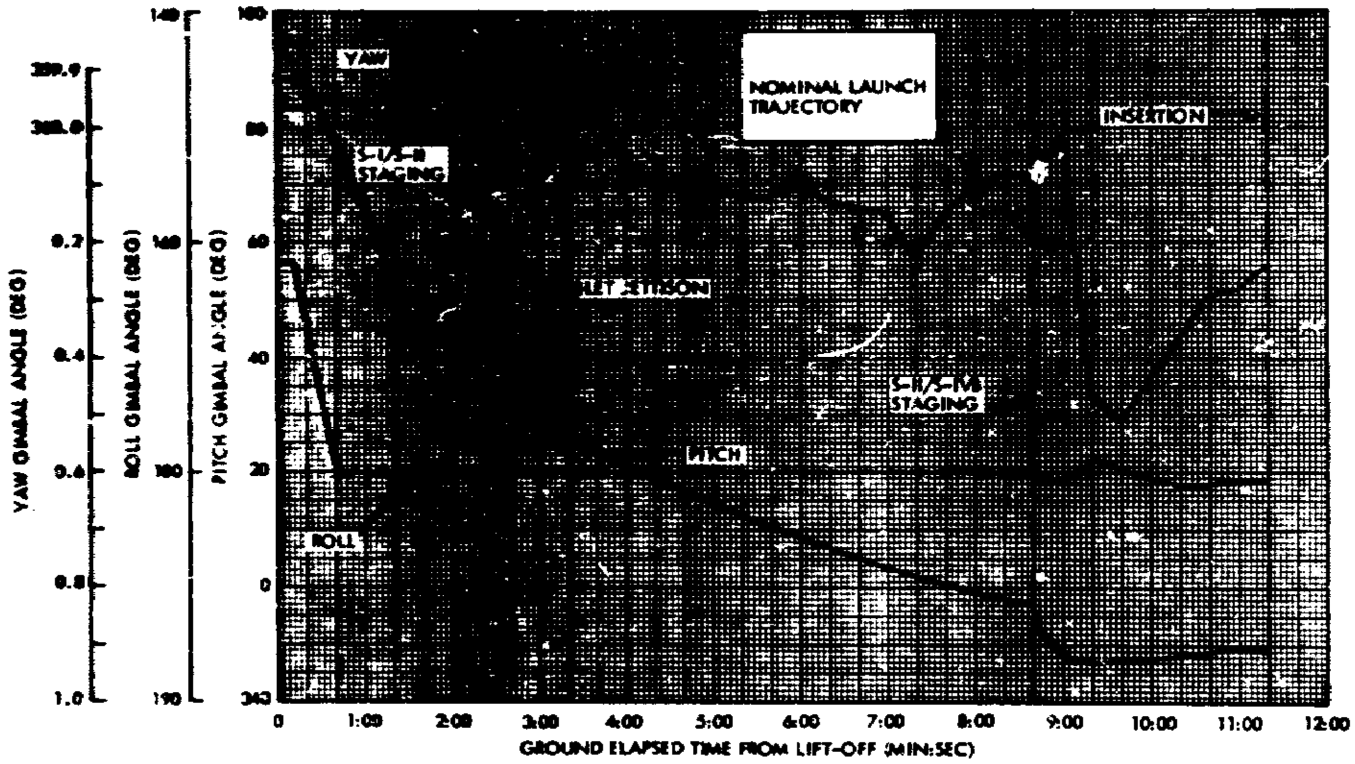


Figure 5-9.- Spacecraft IMU gimbal angle readouts along the nominal launch trajectory.

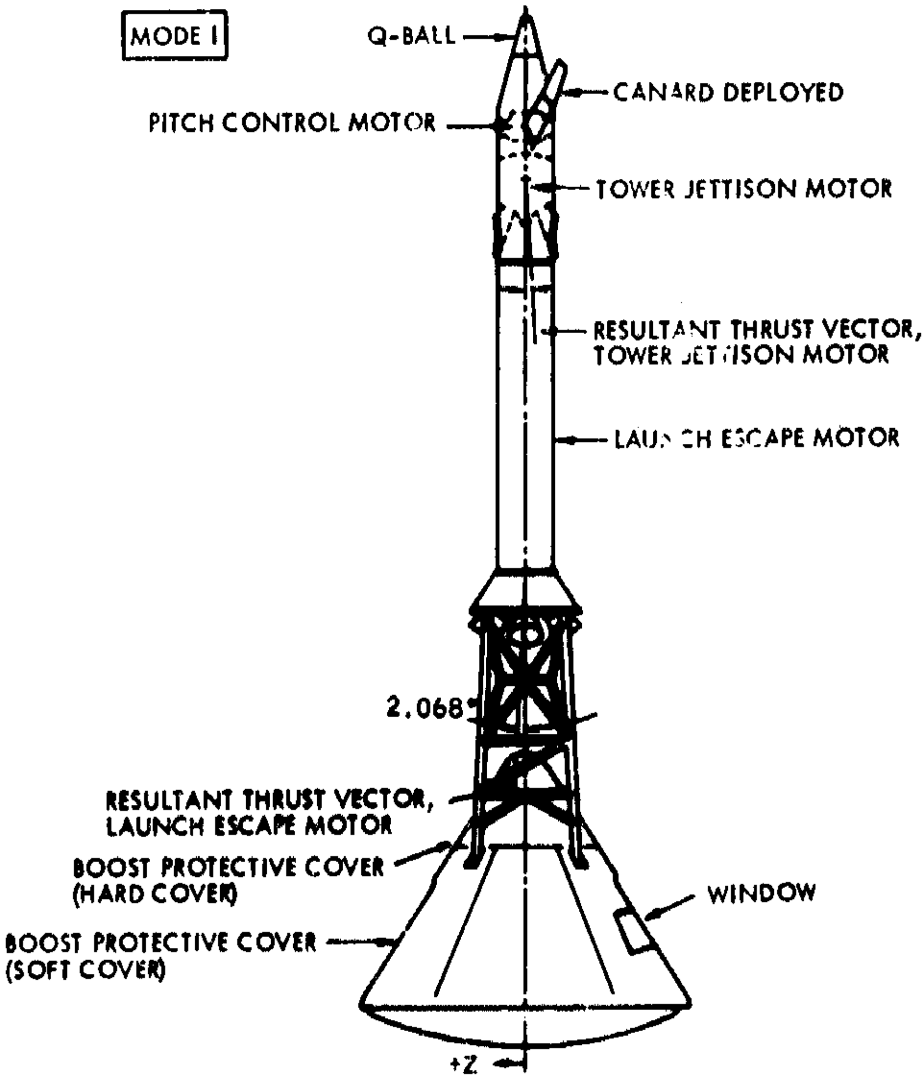


Figure 5-10.- Launch escape vehicle configuration.

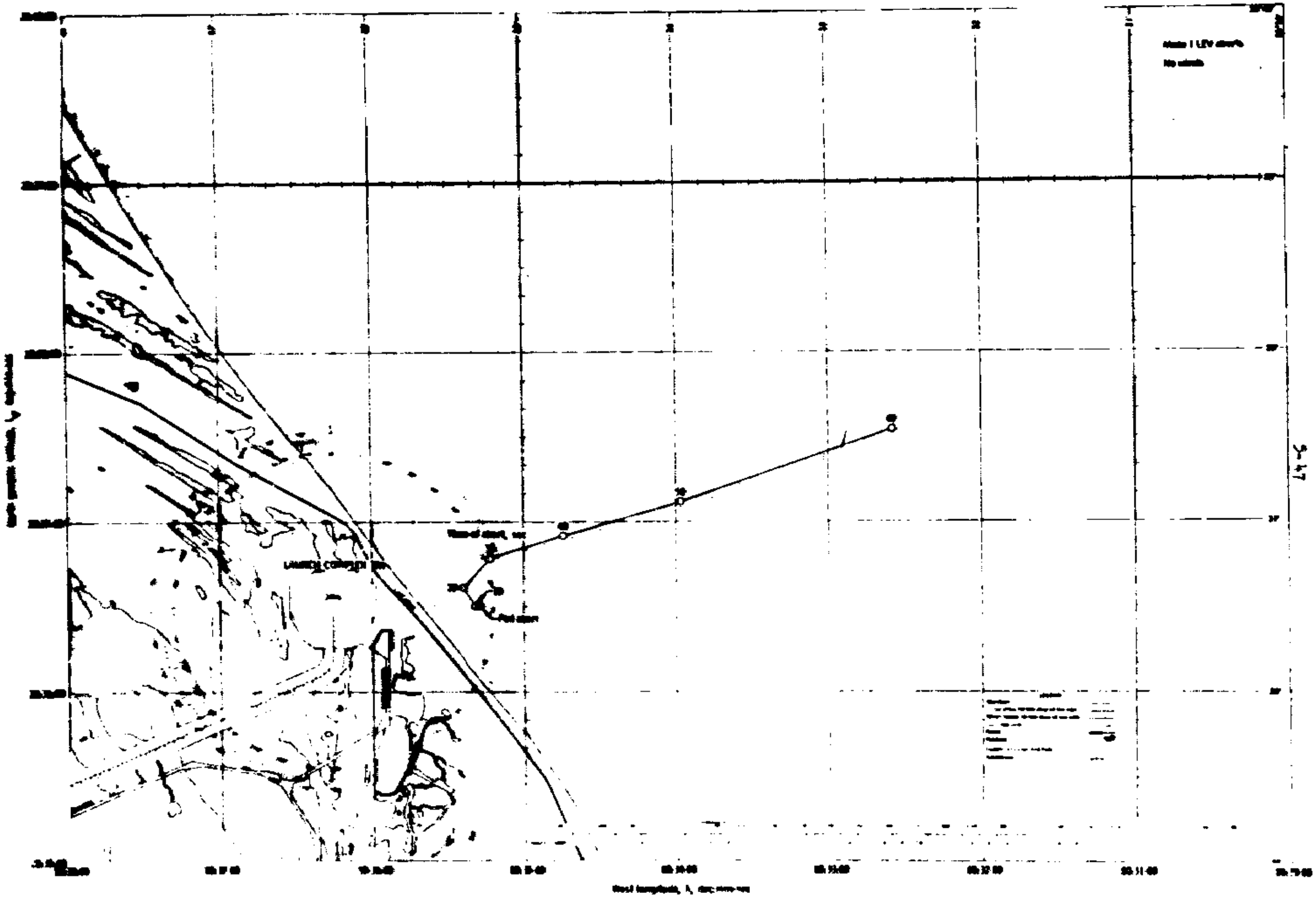


Figure 5-11. - Mode I LEV abort landing points for pad abort through 40 seconds ground elapsed time

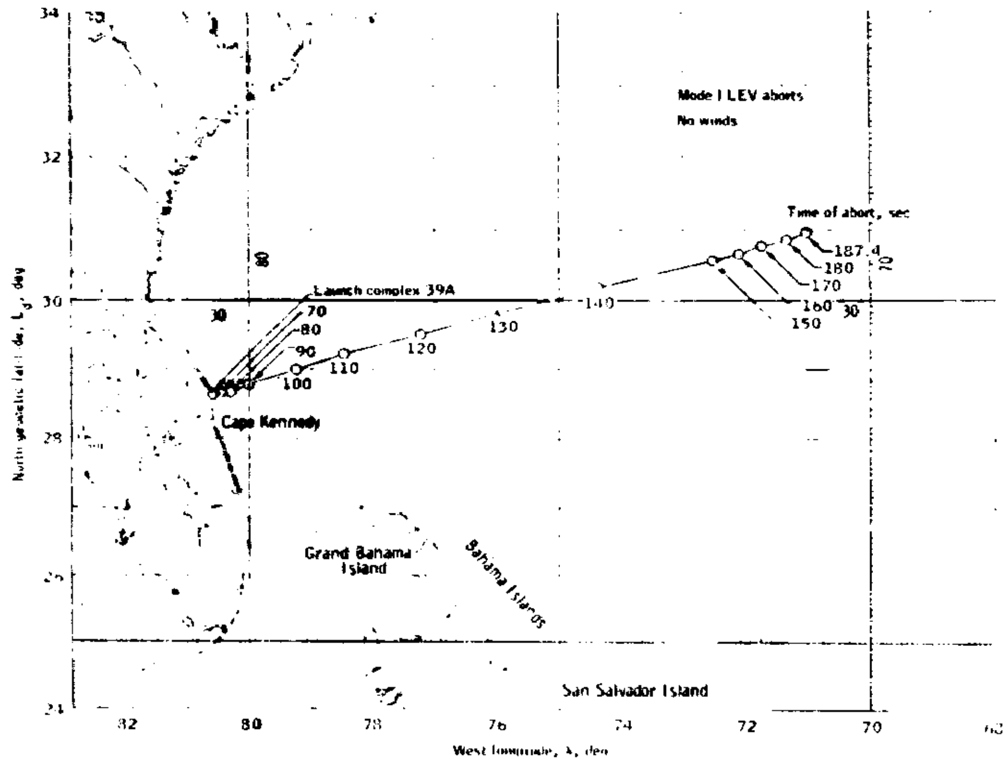


Figure 5-12.- Mode I LEV abort landing points for 70 seconds through 187.4 seconds ground elapsed time.

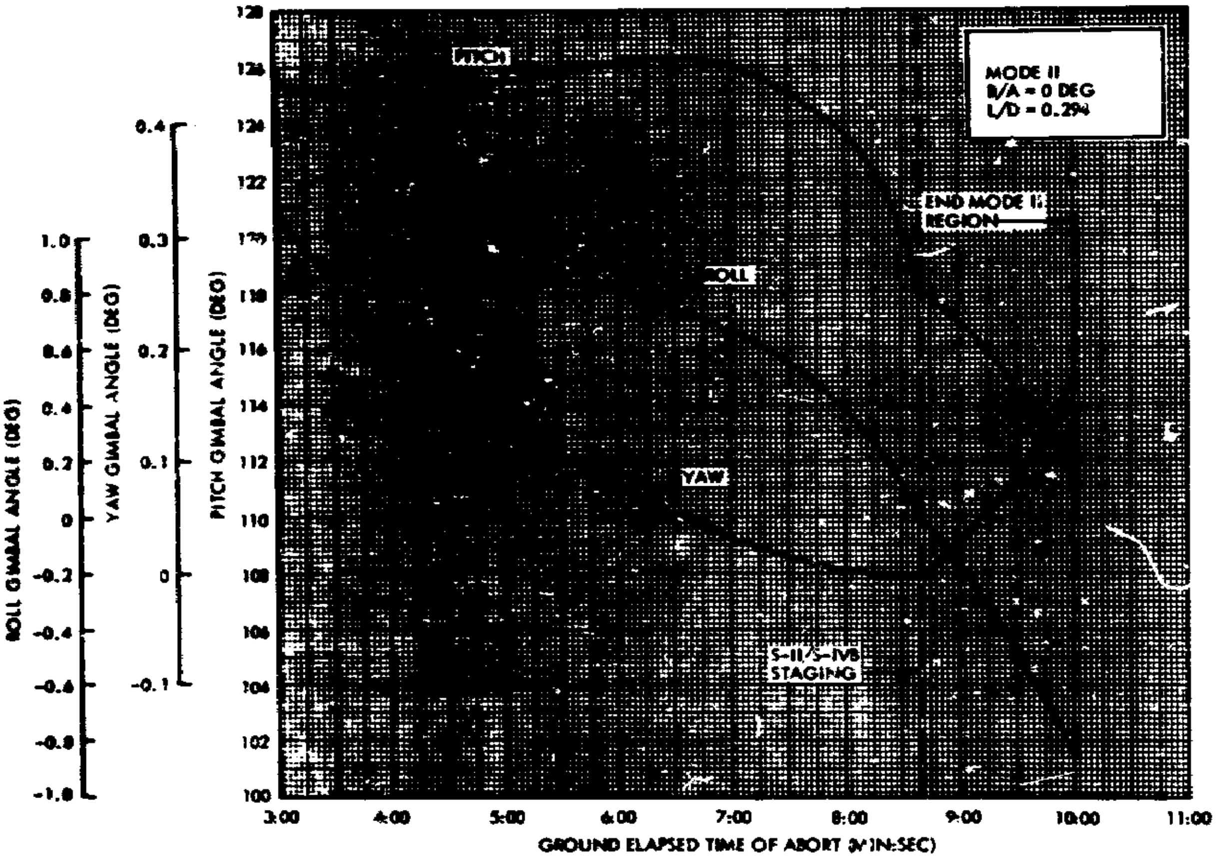


Figure 5-13.- Spacecraft IMU gimbal angle readouts at 0.05g following mode II aborts from the nominal launch trajectory.

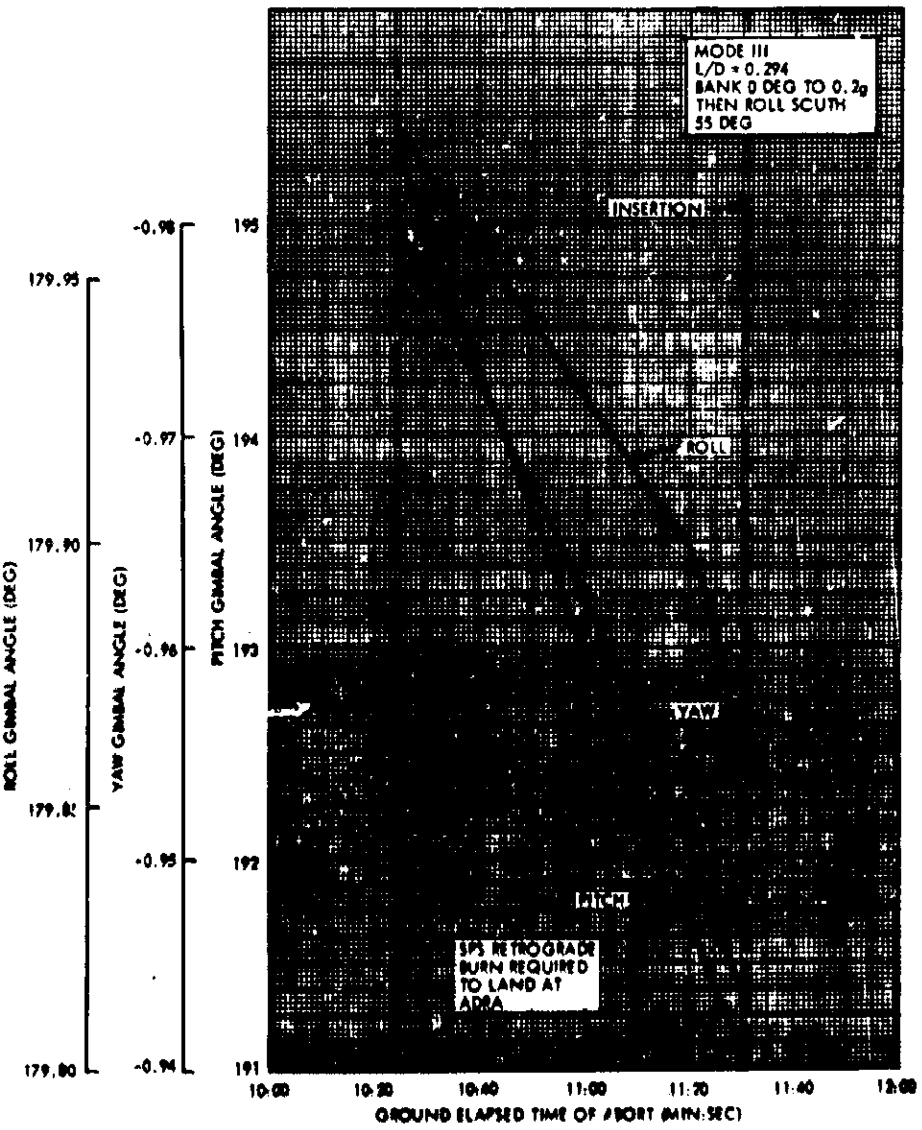
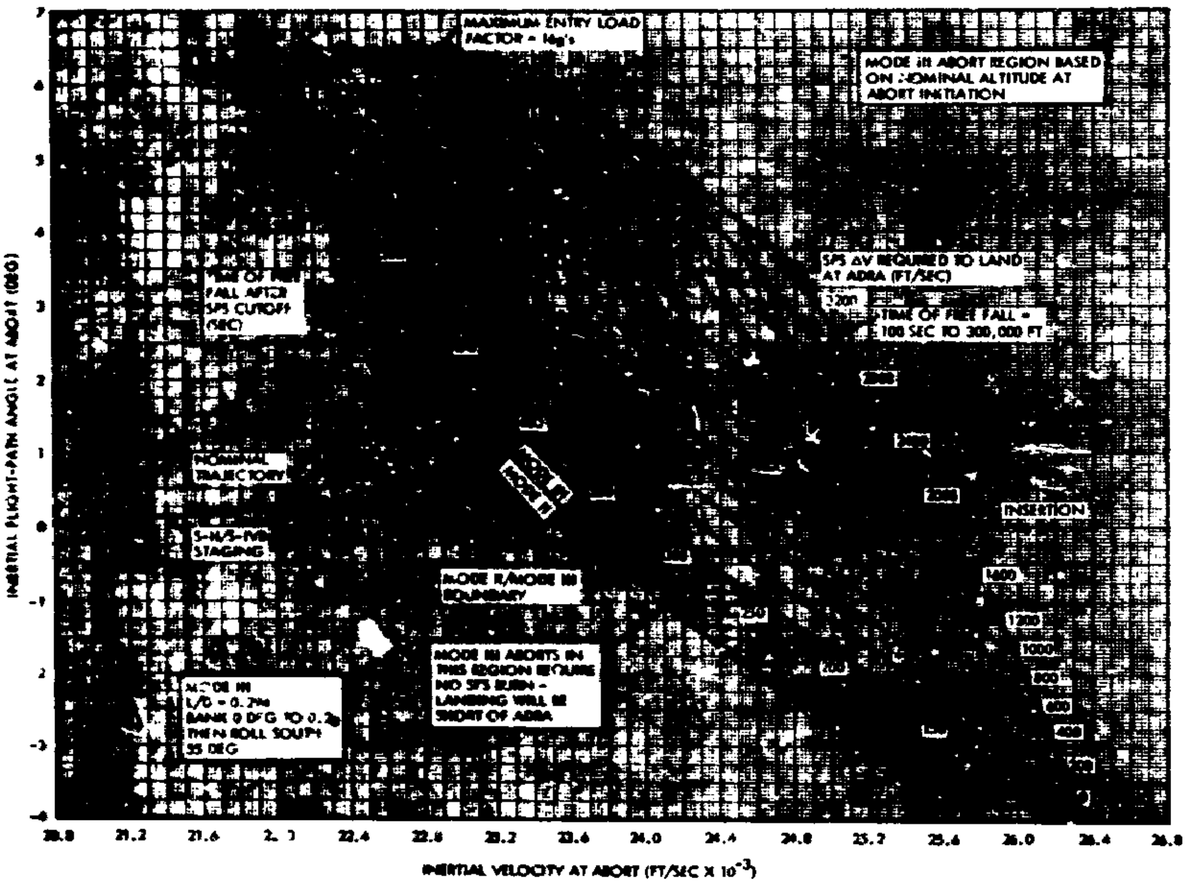
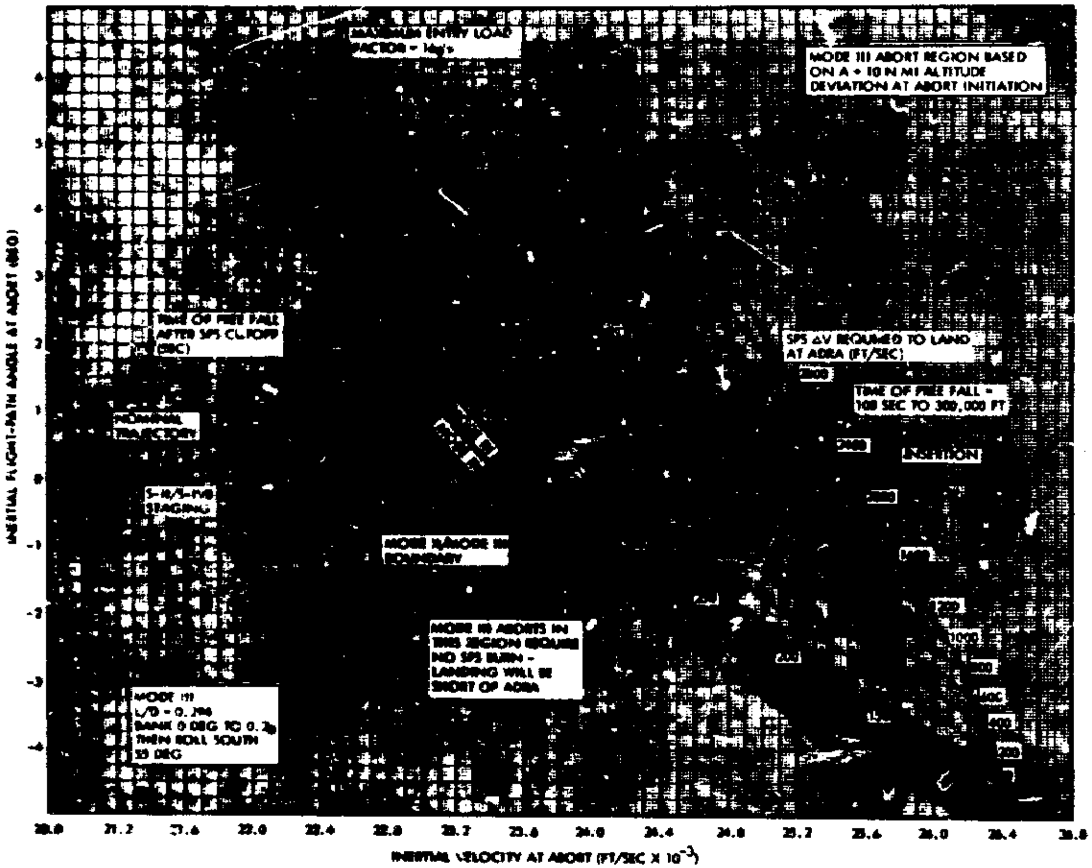


Figure 5-14.- Spacecraft IMU gimbal angle readouts at SPS ignition for mode III aborts from the



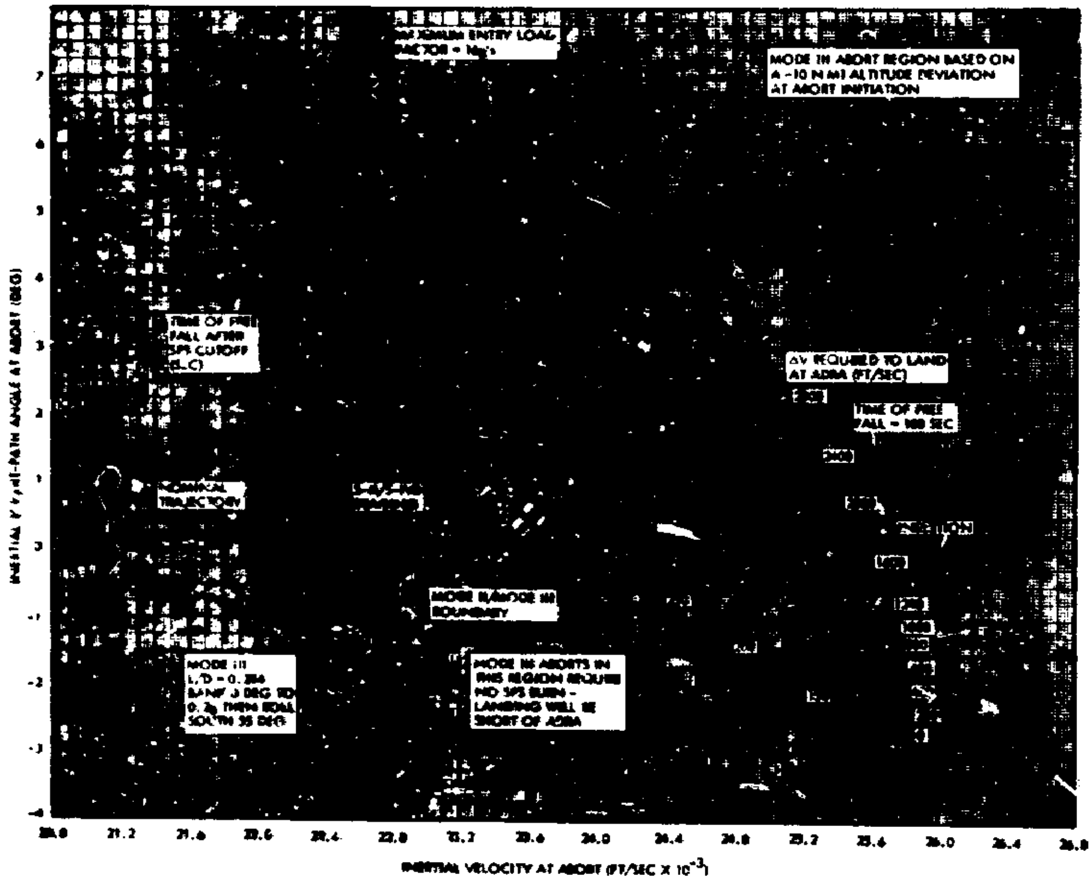
(a) From 103-nautical mile altitude.

Figure 5-15.- Constant mode III ΔV contours required to land at the Atlantic discrete recovery area.



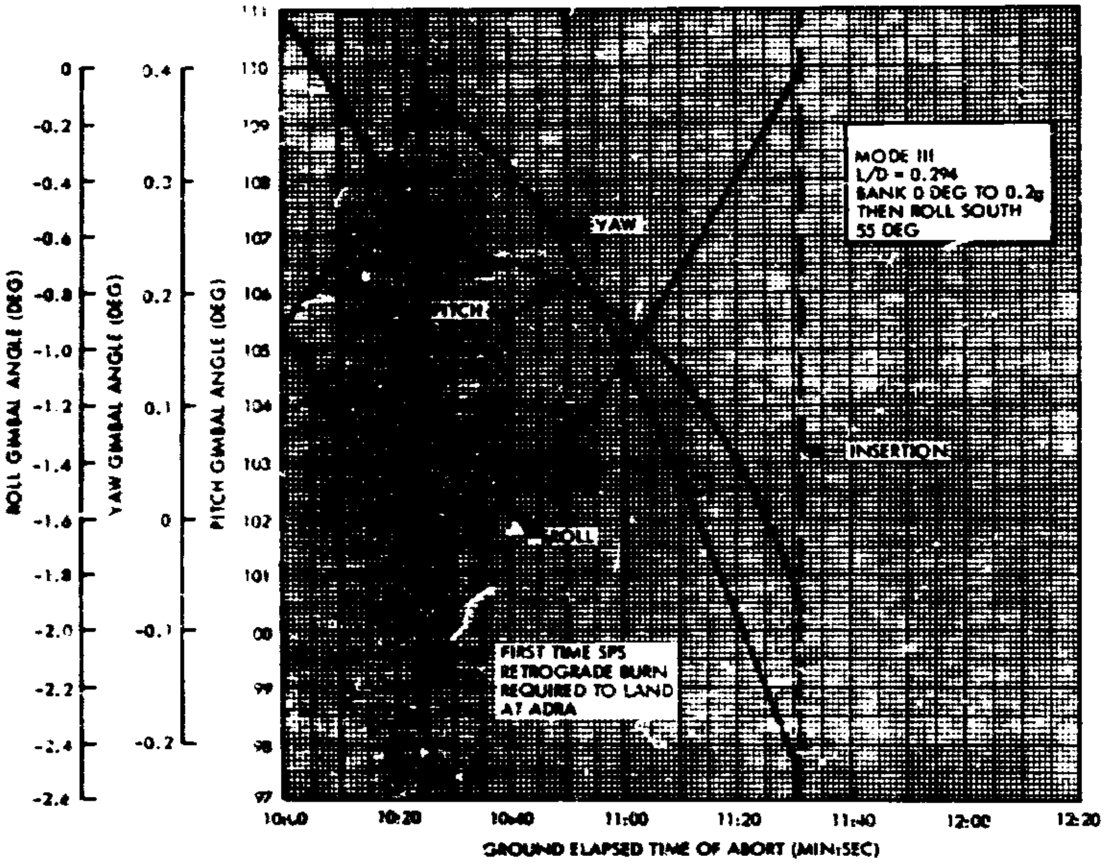
(b) From 113-nautical mile altitude.

Figure 5-15.- Continued.



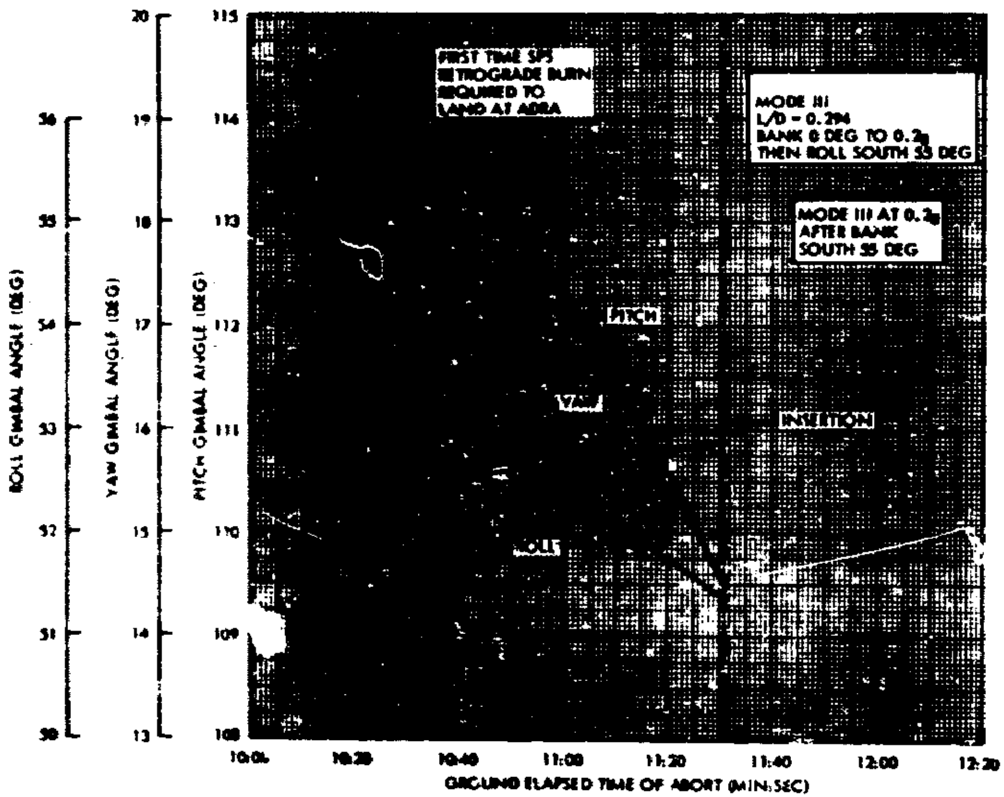
(c) From 93-nautical mile altitude.

Figure 5-15.- Concluded.



(a) 0.05 g.

Figure 5-16.- Spacecraft IMU gimbal angle readouts following mode III aborts from the nominal trajectory.



(b) 0.2 g.

Figure 5-16.- Concluded.

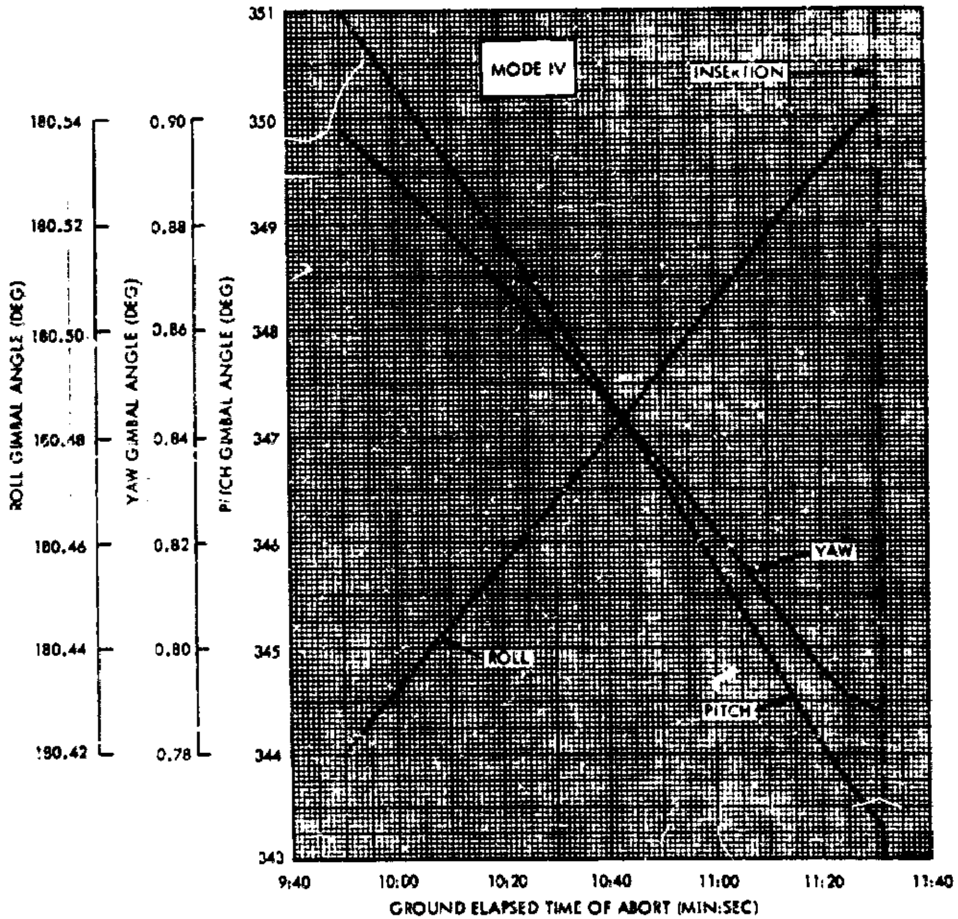
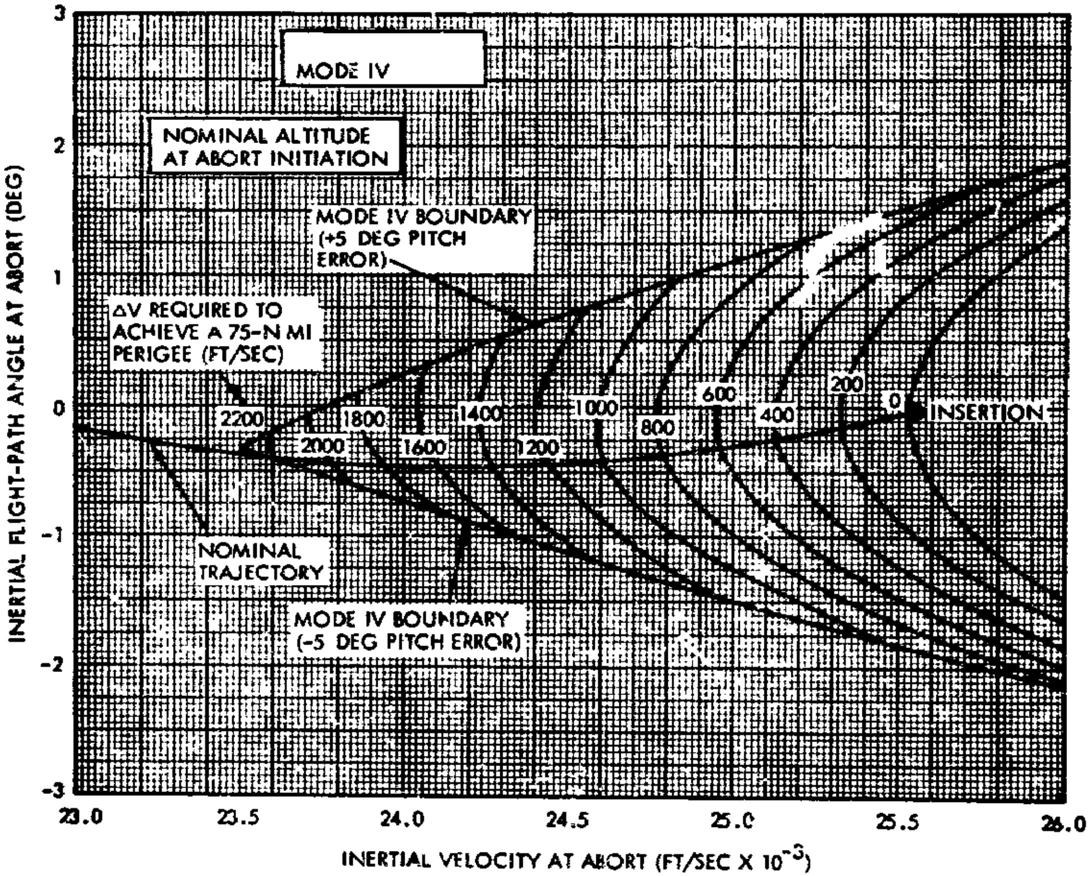
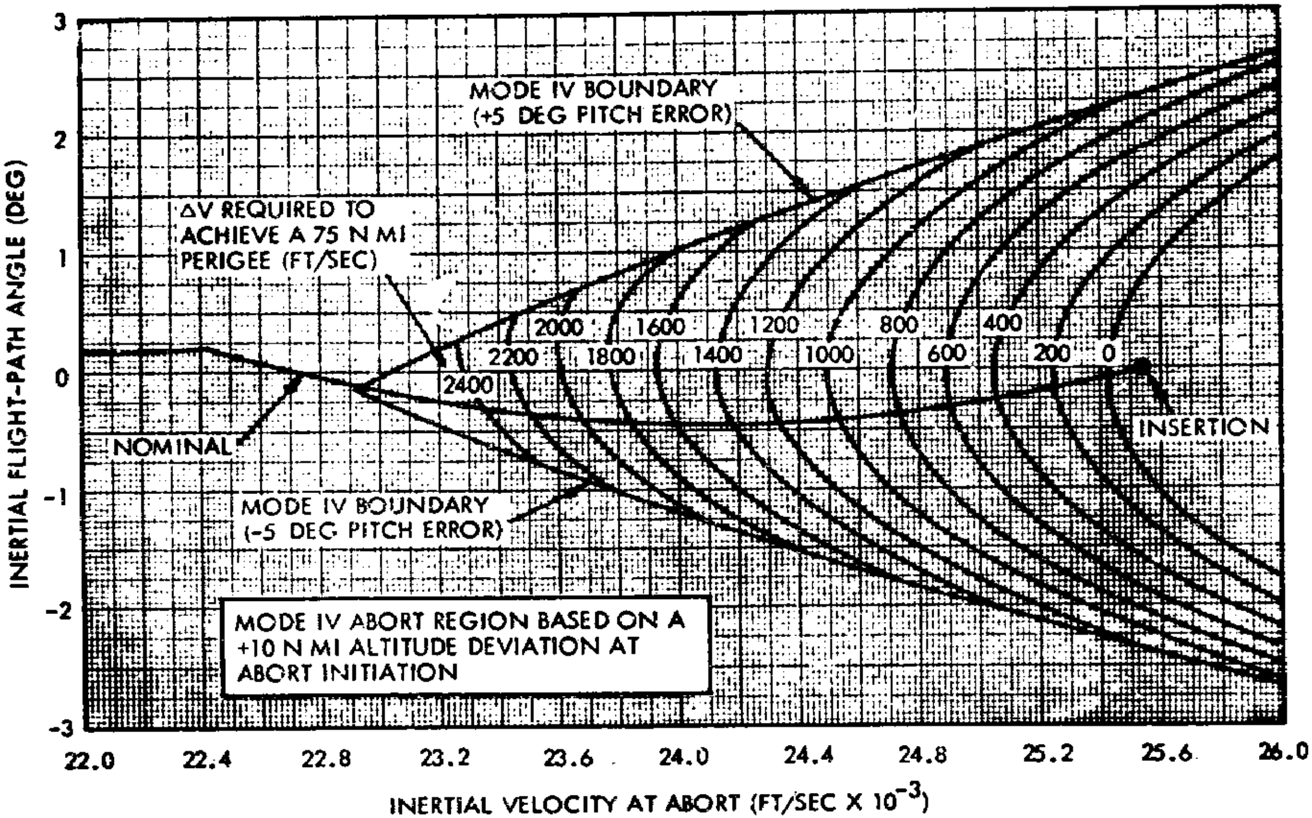


Figure 5-17.- Spacecraft IMU gimbal angle readouts at SPS ignition for mode IV aborts from the nominal trajectory.



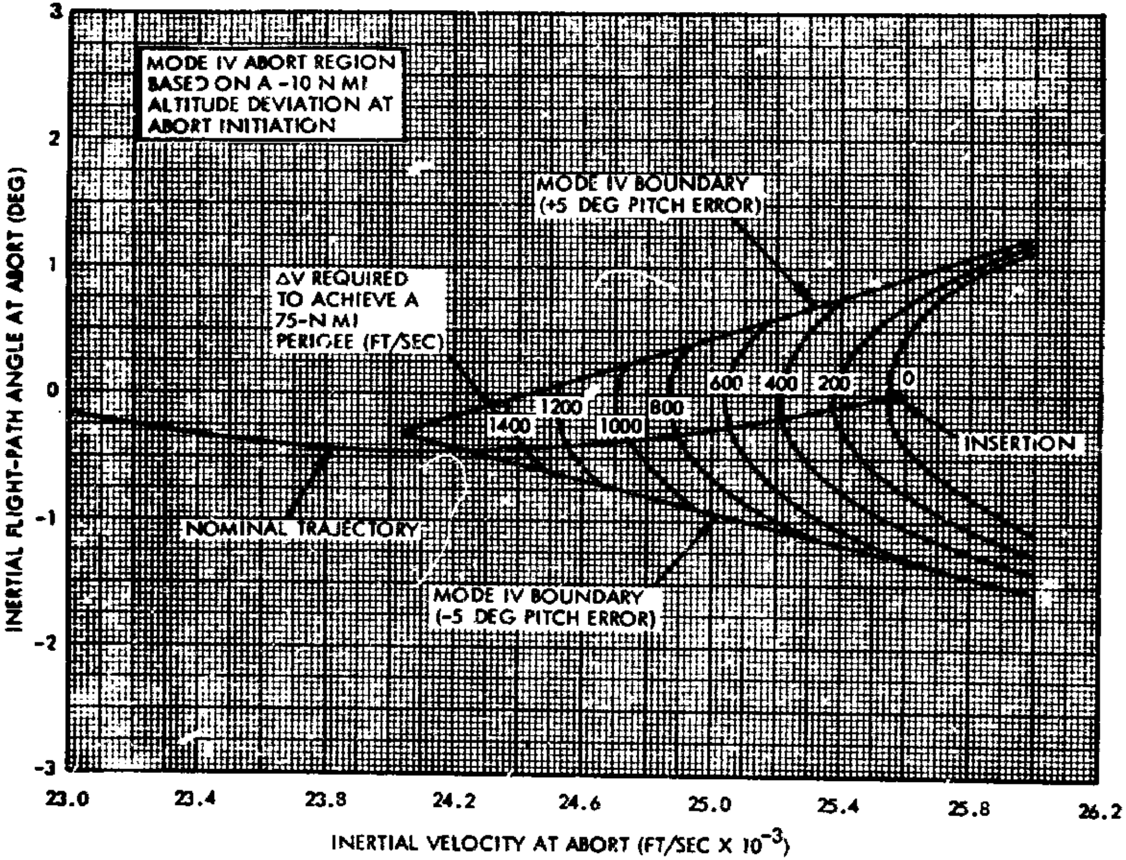
(a) From 103-nautical mile altitude.

Figure 5-18.- Constant mode IV ΔV contours required to achieve a 75-nautical mile perigee altitude.



(b) From 113-nautical mile altitude.

Figure 5-18.- Continued.



(c) From 93-nautical mile altitude.

Figure 5-18.- Concluded.

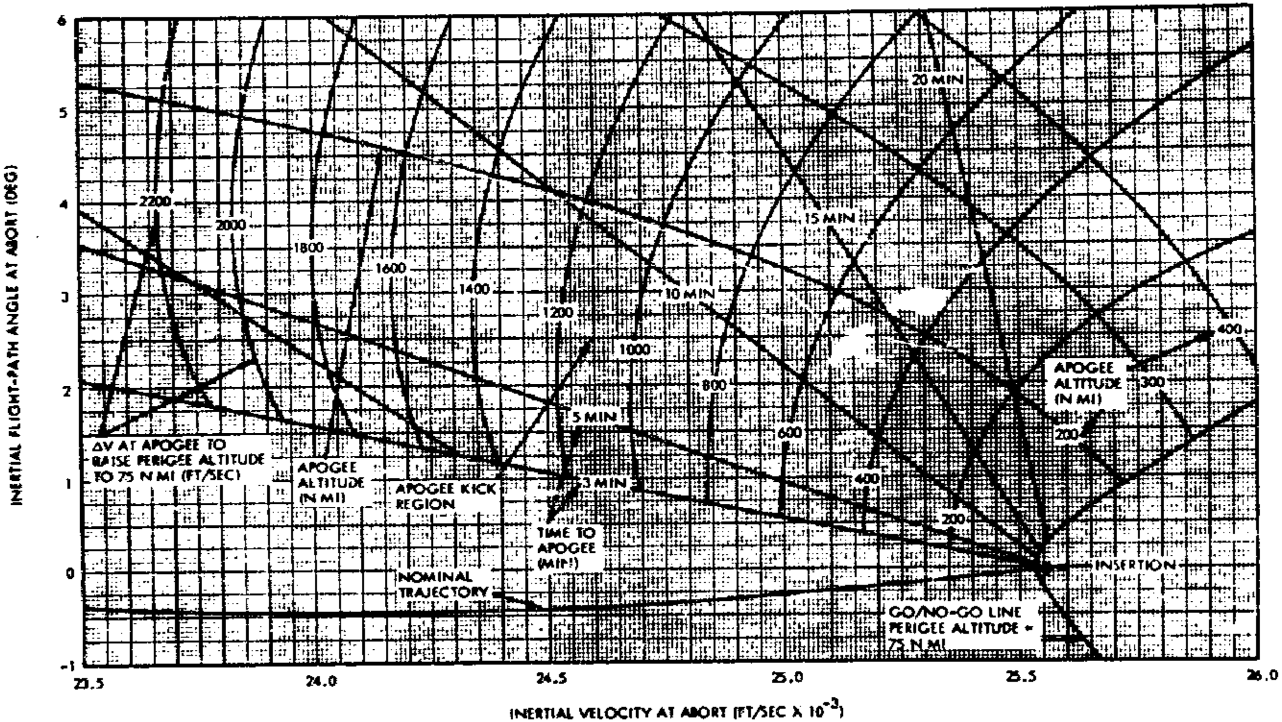


Figure 5-19.- Constant apogee kick ΔV contours required to achieve a 75-nautical mile perigee altitude from 103-nautical mile altitude.

EARTH PARKING ORBIT

6.0 EARTH PARKING ORBIT

Preflight computations for aborting from earth parking orbit are provided the crew and targeted so that the landing occurs in one of three possible areas. Should it become necessary to abort while the crew is out of communication with the ground, a solution would be available. After reaching orbit, the ground updates these solutions so that the crew always has one solution for a revolution ahead of when it would be used. Because this type of abort is well documented (ref. 17), no further information is required of this document.

TRANSLUNAR INJECTION AND
TRANSLUNAR COAST PHASE

7.0 TRANSLUNAR INJECTION AND TRANSLUNAR COAST PHASE

7.1 Translunar Injection Monitoring

As shown in figure 2-1, the primary objective after a problem develops during TLI, as well as all other mission phases, is to perform an alternate mission. However, if the need to abort occurred after a nonnominal TLI maneuver and before the initiation of the alternate mission, the extent of the deviated flight conditions must be known in advance to insure that abort capability will exist. This has been done by the development of a crew monitoring procedure which includes appropriate S-IVB shutdown limits.

The crew must be able to monitor and evaluate TLI without ground support because the maneuver can occur off the MSFN tracking range. In general, TLI occurs at various locations over the west Pacific Ocean and is described by figures 7-1 and 7-2. A schematic of the basic crew monitoring technique is shown in figure 7-3. It is noted that an abort can be performed for S-IVB attitude rate and attitude deviation problems as well as for SC system problems. Since S-IVB problems would normally result in a SC alternate mission, only a critical SC system problem is likely to require an abort.

There are several significant items to be noted about the TLI monitoring technique:

1. TLI will be inhibited if prior to ignition the launch vehicle attitude is more than 10° from nominal as determined by horizon reference.

2. TLI will be shutdown by the crew for S-IVB initiated rates of 10 deg/second.

3. TLI will be shutdown by the crew with the abort handle for attitude excursions of 45° from the nominal attitude as determined by onboard charts of the nominal pitch and yaw gimbal angle histories.

4. A backup to the S-IVB guidance cutoff signal will be performed by the crew if the S-IVB has not shutdown at the end of the predicted burn time plus a 2σ dispersion of 6.0 seconds and if the nominal inertial velocity as displayed by the spacecraft computer has been achieved.

The rationale for the monitoring procedures and the determination of the limits noted above are documented in reference 18, 19, and 20. It is noted that item 3 has the largest impact on possible abort maneuvers since attitude excursions can reduce perigee to as low as

75 n. mi. However, delaying the shutdown to 45° optimizes chances for having time for an entry midcourse maneuver following a TLI abort.

The crew charts noted in item 3 are shown in figures 7-4, 7-5, and 7-6. The double scale on the pitch chart, figure 7-4, indicates the TLI ignition gimbal angle for a 72° launch azimuth. For any other day or azimuth, the crew will renumber the scale by changing the zero point to the ignition pitch gimbal angle uplinked in EPO by the ground. Variations in the inertial pitch and yaw histories are within 4° or 5° for all TLI opportunities in the December window, as shown by figures 7-7 and 7-8. Since the limits of 45° are so wide, it is felt that these variations are relatively small and that the crew charts (figs. 7-4 through 7-6) are adequate for all December TLI maneuvers.

7.2 Aborts from the Translunar Injection and Translunar Coast Phases

7.2.1 <u>Summary and introduction</u>.- This section presents a trajectory analysis of aborts initiated during the second S-IVB burn, immediately following this burn, and on the translunar coast leg of the Apollo 8 mission. It also presents an analysis of abort maneuver dispersions for aborts performed during and immediately following the second S-IVB burn.

The postabort trajectories resulting from early S-IVB shutdown and onboard determination of abort maneuvers may result in land landings following an extremely rapid return flight time from abort to reentry. However, if the S-IVB is allowed to burn to guidance cutoff and an abort maneuver is performed in a time frame allowing IMU alignment, PGNCS targeting and a PGNCS-controlled maneuver, the resulting landing point will be in one of the five CLA's following a return flight time of from 11 to 18 hours.

Aborts performed during the translunar coast phase would normally be targeted to the prime CLA; however, abort trajectory data are presented for aborts to all recovery areas.

The trajectory data included in this section represent the results of digital computer simulations of the abort techniques defined in reference 1.

7.2.2 <u>Data used to generate TLI and TLC abort data</u>.- Inputs used to generate the enclosed abort trajectory data for TLI and TLC aborts include the following:

Abort techniques	ref. 1
Launch vehicle reference trajectory	ref. 3
Entry range functions (only constant-g functions and contingency target line were used).	ref. 21
L/D	0.295
CSM weights and c.g.	ref. 10
SPS thrust and I_{sp}	ref. 22
Reentry corridor	ref. 23

In addition to the above inputs, note that the computer program used to generate the enclosed data was reference 24, which includes the Fischer earth model as the reference ellipsoid. The effects of gravitational perturbations from the oblate earth, triaxial moon, and sun are included.

7.2.3 The 10 minute abort.- The contingencies with which this section is concerned are the spacecraft subsystems problems which can be isolated during TLI and which can result in catastrophe if action is not taken immediately. Note that, at this time, there are no known single point failures which would require the crew to manually shut down the S-IVB and immediately execute an abort maneuver.

It has been recommended in reference 1 and in numerous meetings with Apollo crew members that if the situation permits, the crew should allow the S-IVB to complete TLI, at which time the ground and crew can perform a malfunction analysis to determine the necessity of an abort.

If a critical subsystems failure occurs during TLI and necessitates the shutdown of the S-IVB and the immediate return of the crew to earth, the following sequence will occur leading to the so-called 10-minute abort. This is a fixed attitude abort (attitude is established preflight, fig. 7-9) to be performed 10 minutes after S-IVB shutdown and targeted to the contingency entry target line.

Time from S-IVB cutoff, g.e.t., min:sec	Event
00:00	S-IVB burn time is recorded; THC is turned counterclockwise initiating S-IVB shutdown. Inertial velocity

	(V_i) is recorded from the DSKY. The four +X RCS jets are turned on.
00:03	CSM/S-IVB separation occurs.
00:13	The four +X RCS jets are turned off, and the crew begins pitching up (+X_b down) to -r (down the radius vector) using the earth as the visual reference to determine -r.
01:00	The four +X RCS jets are turned on to initiate an evasive maneuver to provide clearance between the CSM and S-IVB for the abort maneuver.
01:08	The four +X RCS jets are turned off, and the crew begins maneuvering to abort maneuver thrusting attitude (fig. 7-9) driving to the following IMU gimbal angles initially: OGA = 180° MGA = 0.0° IGA = ground computed prior to lift-off.
04:00	The crew selects the abort ΔV from a chart of ΔV versus V_i and S-IVB t_B and enters this value in the ΔV counter. The crew begins preparations for an SCS automatic maneuver.
05:00	The COAS elevation angle is reset to 0°. CDR pilot adjusts his position in the couch to view the horizon through the COAS reticle image.
09:30	The spacecraft is aligned to the required horizon referenced attitude (fig. 7-9).
10:00	The SPS is ignited and the burn is controlled by SCS automatic.

The above timeline has been recommended; however, it should be noted that the controlling timeline will be presented in the Apollo Abort Summary for Apollo 8 to be prepared by the Crew Safety Section, Crew

Safety and Procedures Branch, Flight Crew Support Division.

Figures 7-10, 7-11, and 7-12, which show abort ΔV measured along the X-body axis, SPS abort burn time, and time from SPS abort (SPS off) to reentry as functions of inertial velocity at abort constitute the charts that the crew will need onboard on the day of launch. These figures are double scaled at the top and bottom showing both S-IVB burn time and inertial velocity, respectively. S-IVB burn time is required as the backup independent variable for determining the abort ΔV.

Figure 7-13 shows the landing point loci as a function of S-IVB burn time for three TLI's on the nominal day of launch when the abort ΔV's shown on figure 7-10 were applied at S-IVB cutoff-plus-10-minutes. Shown on figure 7-14 is the ground elapsed time of continuous USBS track as a function of inertial velocity at S-IVB cutoff.

Figure 7-15 shows the altitude at which the CSM would be at abort maneuver initiation as a function of the inertial velocity at S-IVB cutoff.

As indicated in the preceding sequence of events, the ground will provide the crew with the pitch gimbal angle (referenced to the launch pad REFSMMAT) for the crew to use for the initial attitude maneuver for the fixed attitude abort. This gimbal angle remains constant for any shutdown time during TLI. This can be seen in figure 7-16, which shows the IGA (pitch gimbal angle) required for aborting with the fixed horizon referenced attitude at various times from S-IVB shutdown as function of the inertial velocity at S-IVB shutdown. The IGA at 10 minutes remains constant for the full range of TLI velocities. Figure 7-17 shows the IGA at the abort point as a function of the launch azimuth for the planned day of launch.

The primary purpose of the fixed attitude abort is as stated previously: to return the crew to earth as rapidly as possible without regard to landing location.

In order to design this abort to be as insensitive to execution errors as possible, the maneuver is targeted to achieve the midcorridor or contingency entry target line (ref. 21). Also, this is the same entry target line that is stored in the CMC; therefore, subsequent midcourse corrections determined onboard will be targeted to the entry target line used to determine abort ΔV.

Three possible sources of execution errors have been considered in this analysis and their effects shown. Of the three sources studied, ignition time errors and abort ΔV errors have proven to be the least sensitive (i.e., the effect of the errors are more tolerable). The

abort maneuver is very sensitive with respect to attitude errors for aborts performed after about 200 seconds into the TLI burn; however, past this time sufficient time remains prior to entry to perform a midcourse correction back to the entry target line.

Figures 7-18 and 7-19 show the effect of ignition time errors on the fixed attitude aborts if either the nominal horizon reference attitude or the corresponding inertial attitude is used to perform the abort maneuver. These figures show the ignition time can be off by as much as 1 minute and the maneuver can still achieve the entry corridor. The maneuver used at the dispersed ignition times was that used to generate figure 7-10. The actual abort ΔV required at the dispersed ignition times can be determined from figure 7-20, which shows the required abort ΔV for several delay times.

Figure 7-21 shows the tolerable pitch errors for the abort maneuver execution as a function of inertial velocity at S-IVB cutoff. Note that this error can be very large for early shutdown and an accuracy to within 1° is required for a fixed attitude abort following nominal TLI cutoff.

Since the actual maneuver attitude will be determined by visual reference, the degree of execution error can only be determined empirically through simulation. From conversation with Apollo crew members it was found that the expected accuracy in pitch during the attitude alignment is within ±3°. Based on this expected accuracy, it can be seen in figure 7-22 that even if the TLI burn is nominal, if the maneuver is performed at the correct ignition time, and if the correct abort ΔV is used, a MCC will be required for aborts occurring after about 200 seconds into TLI. The expected magnitude of this MCC can be determined from figures 7-23(a) and 7-23(b), which show the MCC ΔV as a function of inertial velocity at S-IVB cutoff for ±3° pitch errors if the MCC is performed at various delay times following the abort maneuver.

Figure 7-24 shows the magnitude of abort ΔV error that can be tolerated and still achieve the entry corridor.

One possible reason that might cause an attitude misalignment when performing the fixed attitude abort maneuver is mistaking the earth's terminator for the horizon. Figure 7-25 shows the pitch error that could result in this instance.

7.2.4 The 90-minute abort.- As stated previously, it has been recommended that, if possible, TLI should always be continued to nominal cutoff, at which time the ground controllers and crew could perform a malfunction analysis to determine the necessity of an abort.

If it is determined that an abort maneuver is required following TLI, the ground and crew will begin preparations leading to an abort maneuver performed approximately 90 minutes from TLI cutoff. Note that the 90 minutes time is not the time of actual SPS ignition. This time has been fixed primarily as input time of ignition for P-37 (onboard return-to-earth abort program) if the crew is ever required to calculate the abort maneuver onboard and to allow the ground computers to perform the same calculations to determine the CM landing point. P-37 will be used to enable the crew to return-to-earth if a critical subsystems failure occurs that requires an abort and ground-to-air communications are lost. The criteria for determining the 90-minute abort ΔV magnitude are:

1. The abort trajectory returns to a CIA.

2. Return flight time does not exceed 18 hours (from TLI cutoff to landing).

3. Abort ΔV does not exceed 7000 fps.

Figure 7-26 shows the time from SPS cutoff to reentry as a function of the abort ΔV required for the 90-minute abort. This indicates the minimum ΔV for the 90-minute abort maneuver is about 4220 fps, which corresponds to the maximum return time of 18 hours.

For the full range of possible abort ΔV's, the earth will always be in view at SPS ignition but a small portion of the earth will be obscured by the lower right-hand side of the left forward viewing window. This is shown in figure 7-27.

Figure 7-28, which shows the pad referenced IMU IGA and the angle between the line of sight to the horizon and the thrust vector, indicates the horizon will appear in the window at about 2.2° above the $X_b - Y_b$ plane (thrust vector is 3.8° below the X-body axis).

Figure 7-29 shows the apparent half angle of the earth (angle between the line of sight to the horizon and the radius vector) as a function of time from S-IVB cutoff and indicates the apparent size of the earth for various abort ΔV's.

For the nominal spacecraft trajectory the 90-minute abort will require an abort ΔV of 5125 fps, and the resulting landing point will

be in the Atlantic Ocean recovery area. SPS ignition for this maneuver occurs 86.5 minutes from TLI cutoff or at $04^h22^m12^s$ g.e.t. for the December 21, 72° launch azimuth, first-opportunity TLI.

Maneuver execution errors of less than 1° in pitch attitude for the 90-minute abort can cause the entry vector to lie outside the entry corridor. The MCC ΔV magnitude required to correct for execution errors is a function of the time of MCC, the magnitude of the error, and the purpose of MCC. If the MCC is designed to retarget to the original landing point (preabort computed landing point) the magnitude grows as a function of delay time from SPS abort cutoff. If the MCC is designed to retarget to the entry corridor only, the optimum orbital position to perform MCC is at apogee of the postabort trajectory. Thus, the optimum time from MCC to the entry corridor is a function of postabort true anomaly, which, in turn, is a function of the abort ΔV.

Figure 7-30 shows the MCC ΔV required to achieve the entry corridor only as a function of delay time from SPS abort cutoff for several pitch errors at the abort point.

Figure 7-31 shows the MCC ΔV required to achieve the preabort-computed landing point as function of delay time from SPS abort cutoff for several pitch errors at the abort point.

7.2.5 Translunar coast aborts.- In earth parking orbit, prior to TLI, the ground controllers will pass to the crew two abort solutions based on a nominal TLI burn. The first solution, the 90-minute abort, is provided to be used if a critical subsystem fails and ground to air communications are lost following TLI. The second solution is provided to be used if no critical subsystems failure has occurred but ground to air communications cannot be established following TLI. In both instances, it is recommended that the crew retarget the abort maneuver onboard using P-37. This is done to account for any trajectory dispersions which might be induced by the S-IVB during TLI.

Following TLI, the ground controllers will periodically provide abort solutions (block data) to the crew to be used if spacecraft communications fail. In these instances, it is also recommended that P-37 be used for MCC following the abort maneuver.

The block data solutions provided the crew during TLC will be targeted to return to the prime CLA located in the middle of the Pacific Ocean. This does not preclude the targeting of abort solutions to any of the four remaining contingency areas or returning the crew to an unspecified water landing area if the situation warrants such action.

For abort maneuvers targeted to an unspecified area, the return time is simply a function of orbital position (delay time from S-IVB cutoff) and the ΔV expended. This is shown in figure 7-32, which presents the time from abort to reentry (TAR) as a function of the delay time from S-IVB cutoff for several abort ΔV's. Note that after about 36 hours the total ΔV available (about 10 000 fps) could not be used without violating the maximum reentry velocity. Figure 7-33 shows the total flight time (time from S-IVB cutoff to landing) as a function of entry velocity and delay time for several abort ΔV's. The effect on entry velocity of using various amounts of abort ΔV on entry velocity can be seen more readily in figure 7-34 which shows entry velocity as a function of delay time for several abort ΔV's.

As mentioned previously, the thrust vector for the 90-minute abort is about 6° below the crew line of sight to the horizon, or about 6° between the radius vector and the thrust vector with the earth in the window at SPS ignition. As the spacecraft moves farther out on the TLC, the angle between the thrust vector and the radius vector decreases. Also, the attitude difference between very small ΔV abort maneuvers and very large ΔV abort maneuvers decreases. After about 4 hours on the TLC, the angle between the thrust vector and the radius vector is about 2°, and the attitude difference between small and large ΔV maneuvers is less than 1°. At the last block data abort point on TLC, the thrust vector is aligned along the radius vector.

This phenomenon then always allows the earth to be used as a visual reference for the TLC return-to-earth maneuver. Also, since we know the attitude difference between the very small ΔV's and very large ΔV's to be very small, the abort targeting to contingency landing areas can easily be explained in terms of abort ΔV and return time. Suppose at some time on the TLC an abort solution is found which returns to one of the five contingency areas (fixed longitude); that solution will require x-fps abort ΔV and will return in y hours. For that same delay time several solutions exist that return the SC to that same contingency area. If more ΔV is applied at nearly the same attitude, the return time is shortened, and if less ΔV is applied, the return time is lengthened. To find the other solutions, the ΔV must be increased sufficiently to shorten the return flight time by exactly 24 hours or decreased to lengthen the flight time by 24 hours. This can be seen in figure 7-35, which shows the abort ΔV required to achieve the required total flight times to the various contingency areas as a function of delay time from S-IVB cutoff. For any given delay time, several solutions to the same contingency area exist with a difference in return time of 24 hours.

Figure 7-36 shows the latitude of landing for applying various ΔV's at various delay times if the solution achieves the contingency area.

The RTCC displays this type of information to the flight controllers for abort planning and for a first guess to subsequent abort processors. Once the final desired abort solution has been selected, the flight controller will generate a set of digital information and a target load for each abort solution.

All planned maneuvers on Apollo 8 will be performed using the external ΔV guidance in the CMC. Table 7-I presents representative information that will be included as part of the block data information to be provided the crew periodically during TLC.

Figure 7-37 shows postabort ground tracks that would result from employing the abort solutions in Table 7-I. Figure 7-38 shows postabort tracking from the 14 listed MSFN sites.

TABLE 7-1. - BLOCK DATA FOR TRANSLUNAR COAST ABORTS

Abort, g.e.t., hr:min:sec	Approximate time from TLI cutoff, hr	IMU gimbal angles referenced to launch pad			ΔV_T, fps	Δt_B, min:sec	TAR, hr:min:sec	V_{EI}, fps	γ_{EI}, deg	ϕ_L, deg	λ_L, deg	External ΔV targets		
		OGA, deg	IGA, deg	MGA, deg								ΔV_X, fps	ΔV_Y, fps	ΔV_Z, fps
[illegible]:25:42.71	1.5	178.03	168.53	358.96	5125.0	06:28.4	12:53:53	34376.95	-7.27	07.14	330.96	-422.27	000.00	5107.69
[illegible]	4.0	177.29	153.99	359.59	5543.4	06:52.2	19:14:19	34473.11	-6.35	06.62	194.99	-150.75	000.00	5541.40
[illegible]	11.0	176.91	143.33	000.16	4759.2	06:06.7	36:23:03	35523.11	-6.42	08.28	194.96	-045.63	000.00	4758.98
[illegible]	25.0	177.15	136.55	000.51	5319.2	06:39.6	46:14:21	35809.36	-6.46	07.67	194.86	-007.58	000.00	5319.22
[illegible]	35.0	358.24	141.44	355.86	4703.7	06:03.4	69:17:18	35904.60	-6.48	09.74	195.01	014.08	000.00	4703.72
[illegible]	44.0	000.11	140.11	355.98	6108.9	07:22.9	51:05:16	36039.56	-6.49	06.63	194.52	026.53	000.00	6108.87
[illegible]	63.0*	354.64	110.16	005.11	1101.7	01:40.8	61:06:36	36034.79	-6.50	10.54	195.03	-020.50	000.00	-1101.46

*Gimbal angles referenced to "LOI(2) reference".

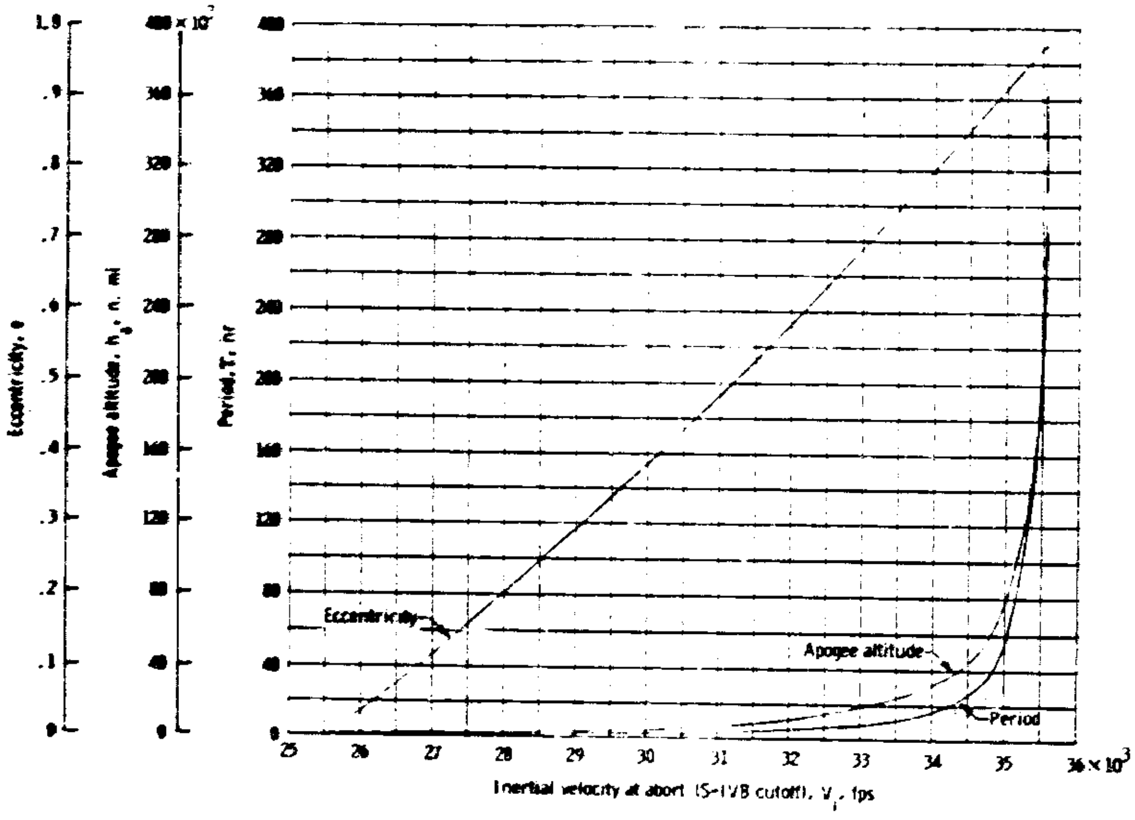


Figure 7-L.- Orbital parameters as functions of inertial velocity during the translunar injection burn.

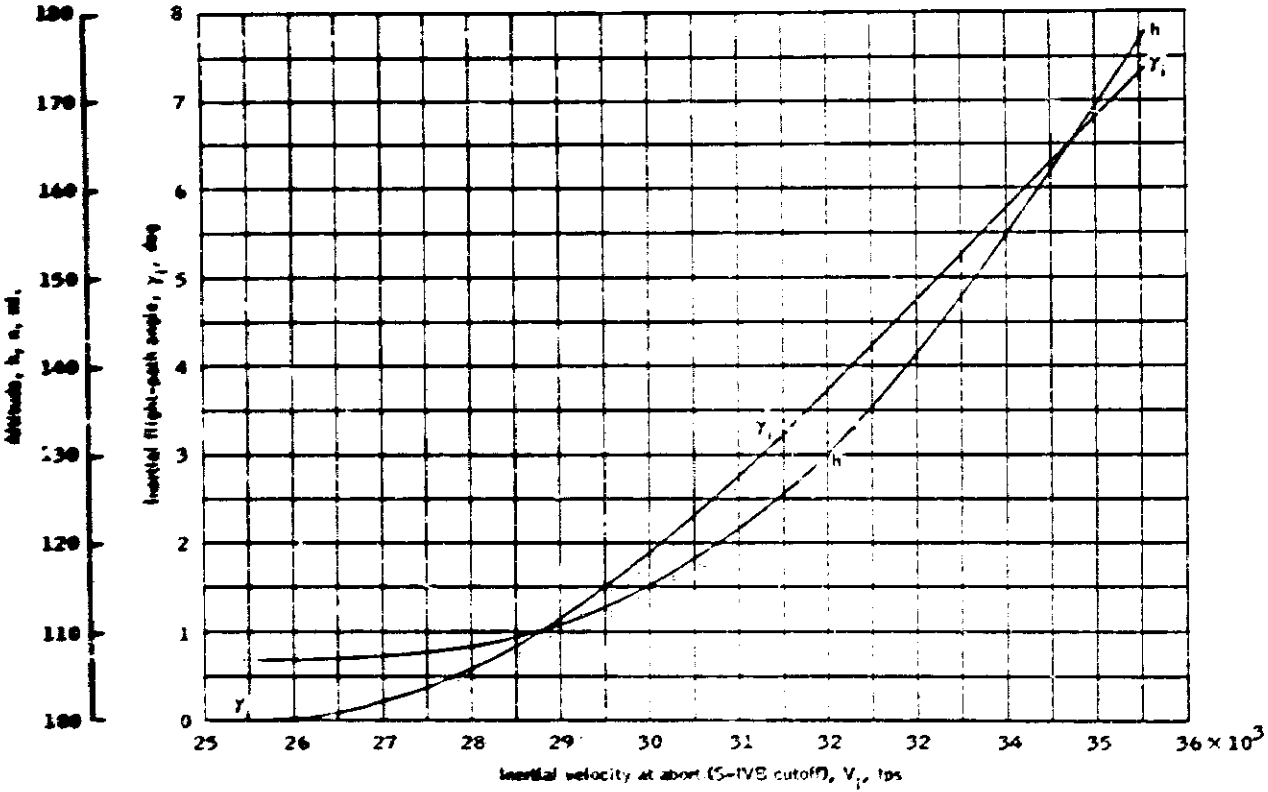


Figure 7-2.- Altitude and inertial flight-path angle as functions of inertial velocity during the translunar injection burn.

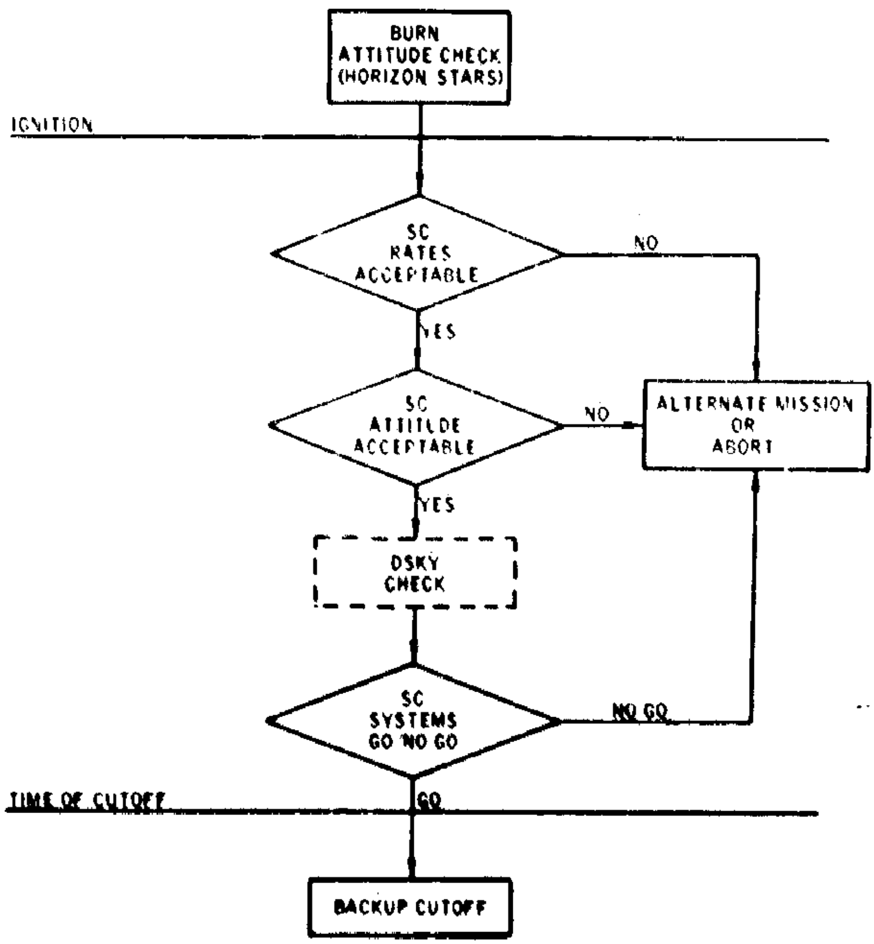


Figure 7-3. - Basic crew maneuver monitoring technique.

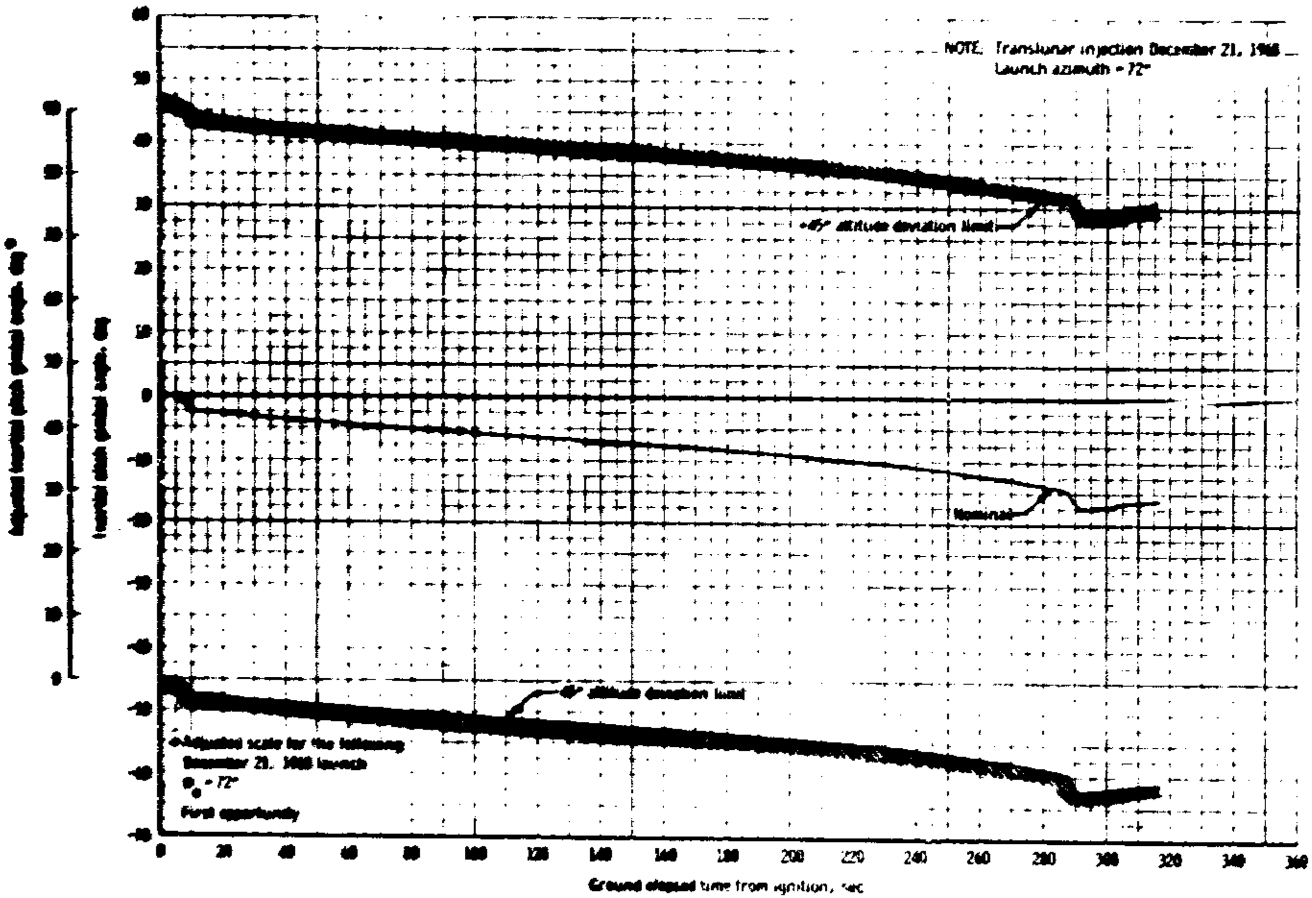


Figure 7-4. - TLI pitch gimbal angle history and attitude deviation limits for first opportunity.

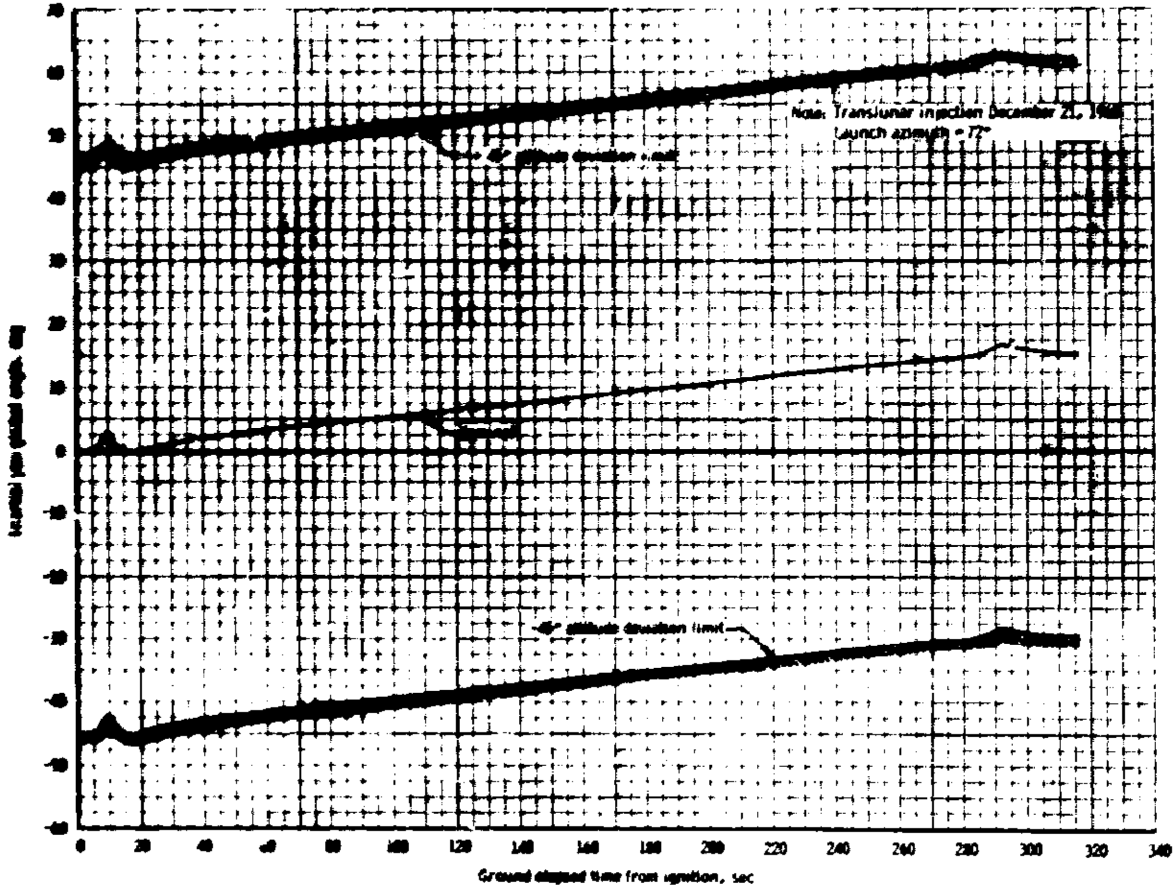


Figure 7-4. - TLI yaw gimbal angle history and attitude deviation limits for first opportunity.

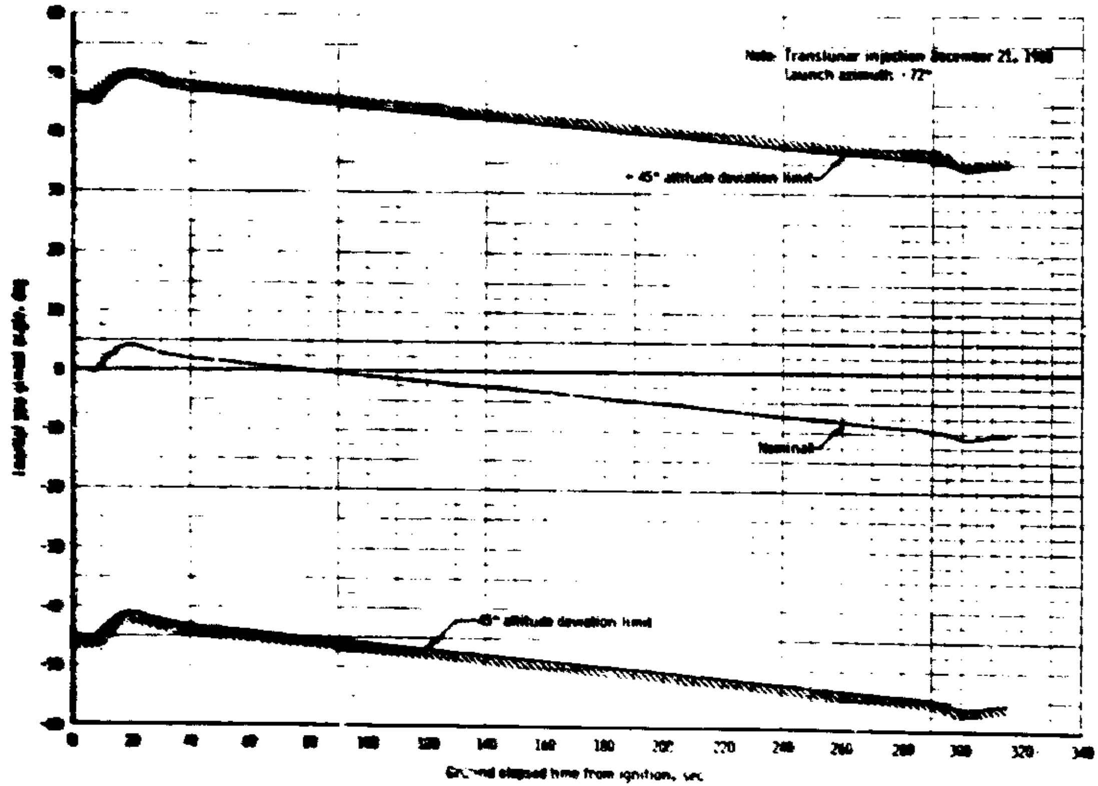


Figure 7-6.- TLI yaw gimbal angle history and attitude deviation limits for second opportunity.

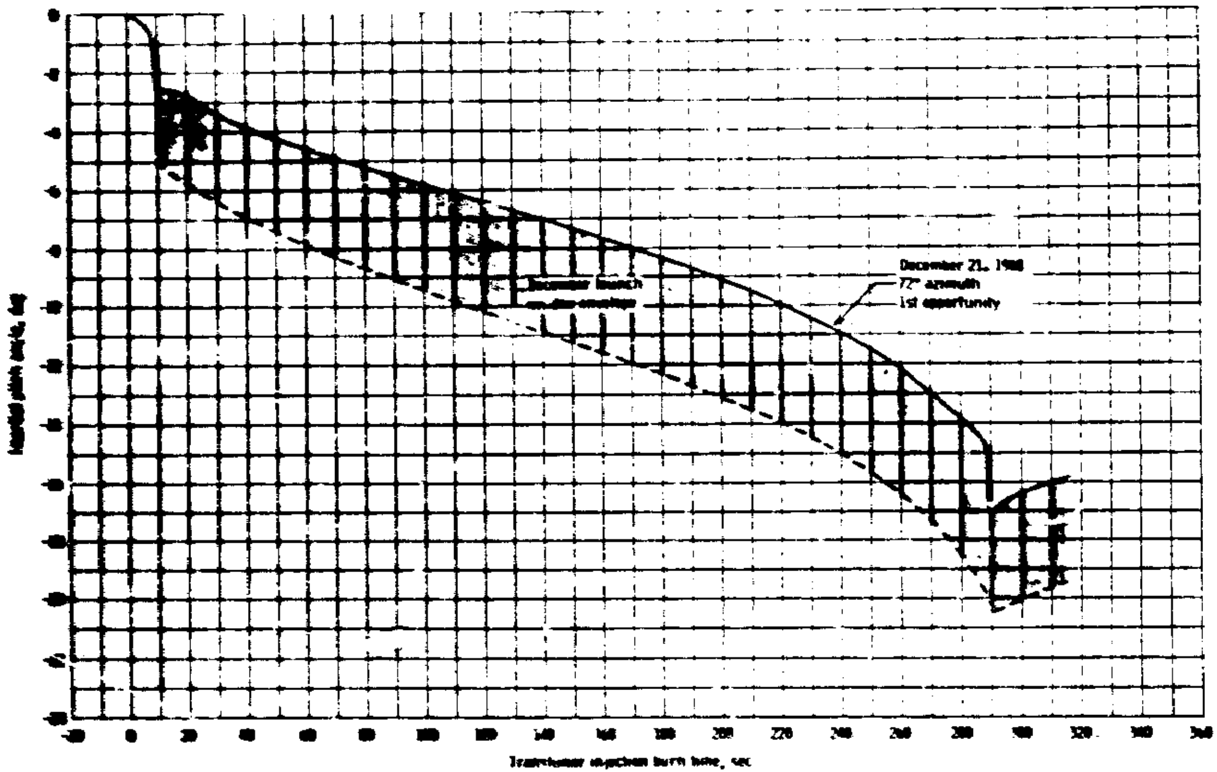


Figure 7-7.- Envelope of December launch window pitch angle excursions through TLI.

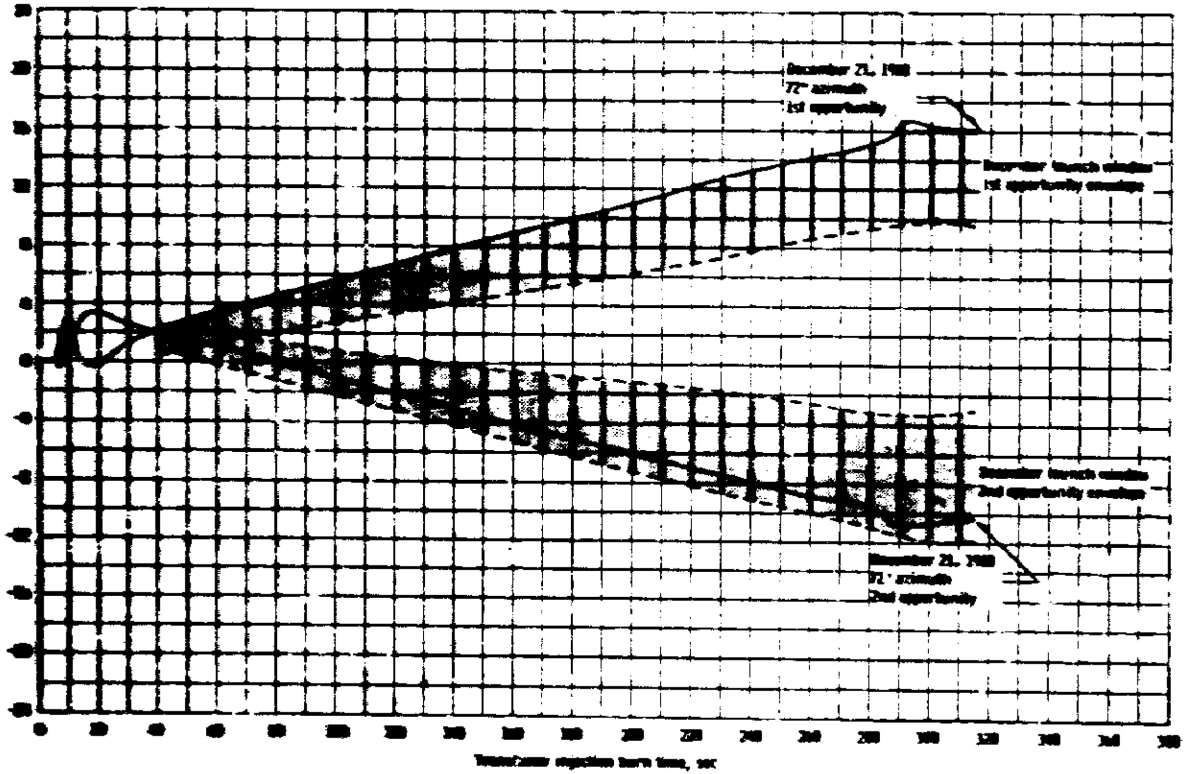


Figure 7-[illegible]. - Envelope of December launch window yaw excursions through TLI.

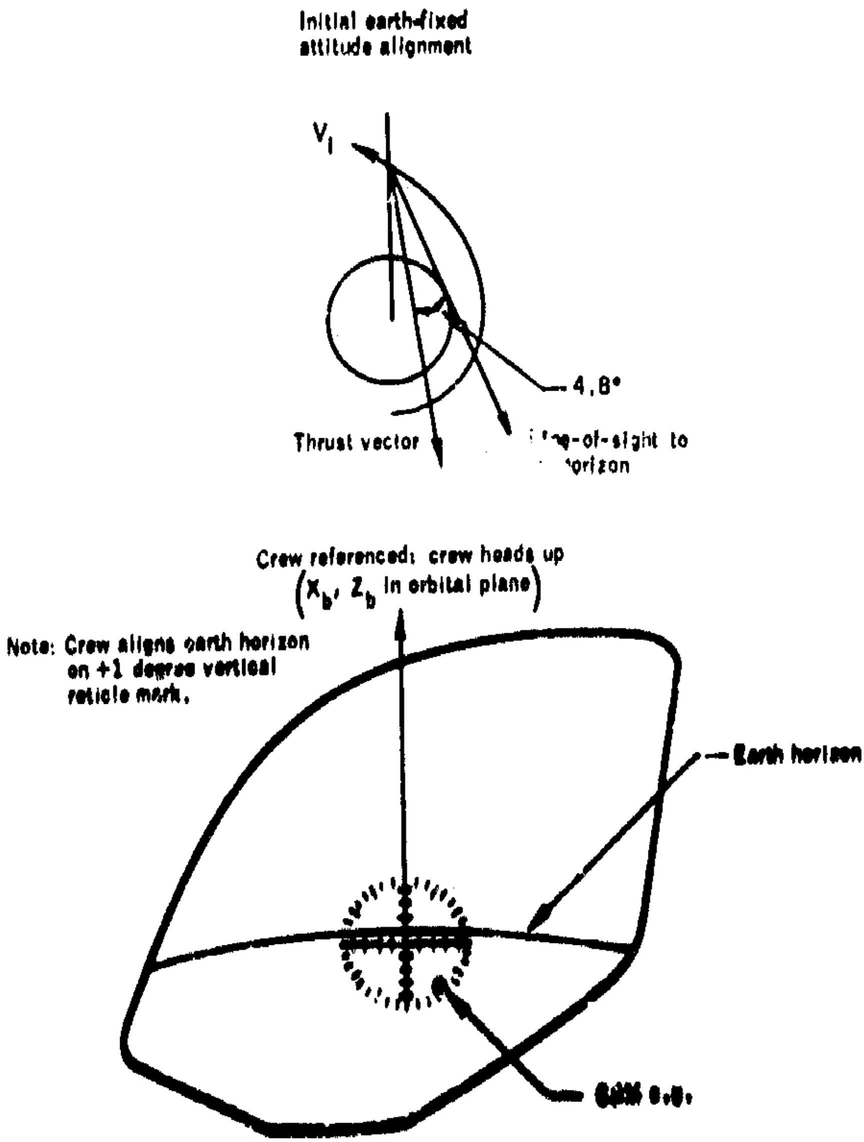


Figure 7-9.- Definition of attitude for fixed aborts from TLI.

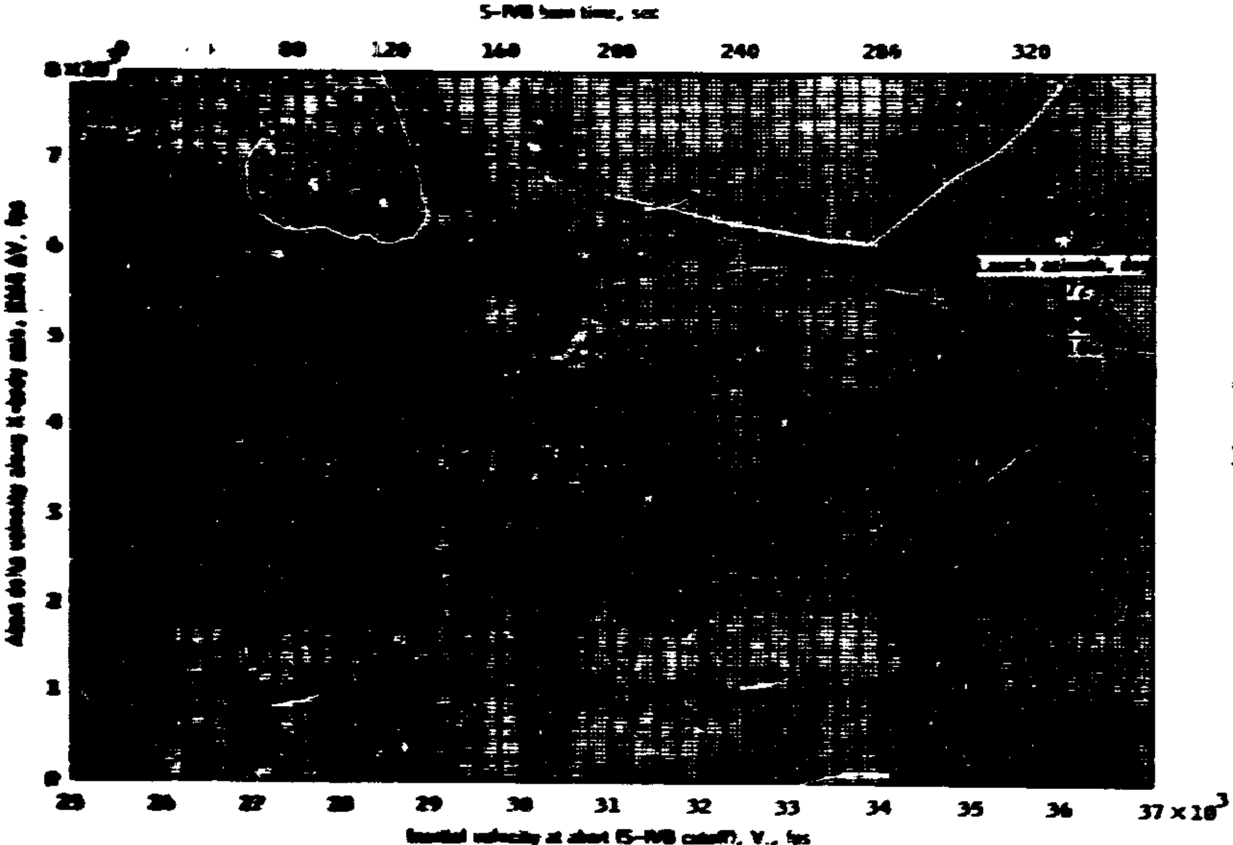


Figure 7-30.- EMS delta velocity as a function of inertial velocity at abort.

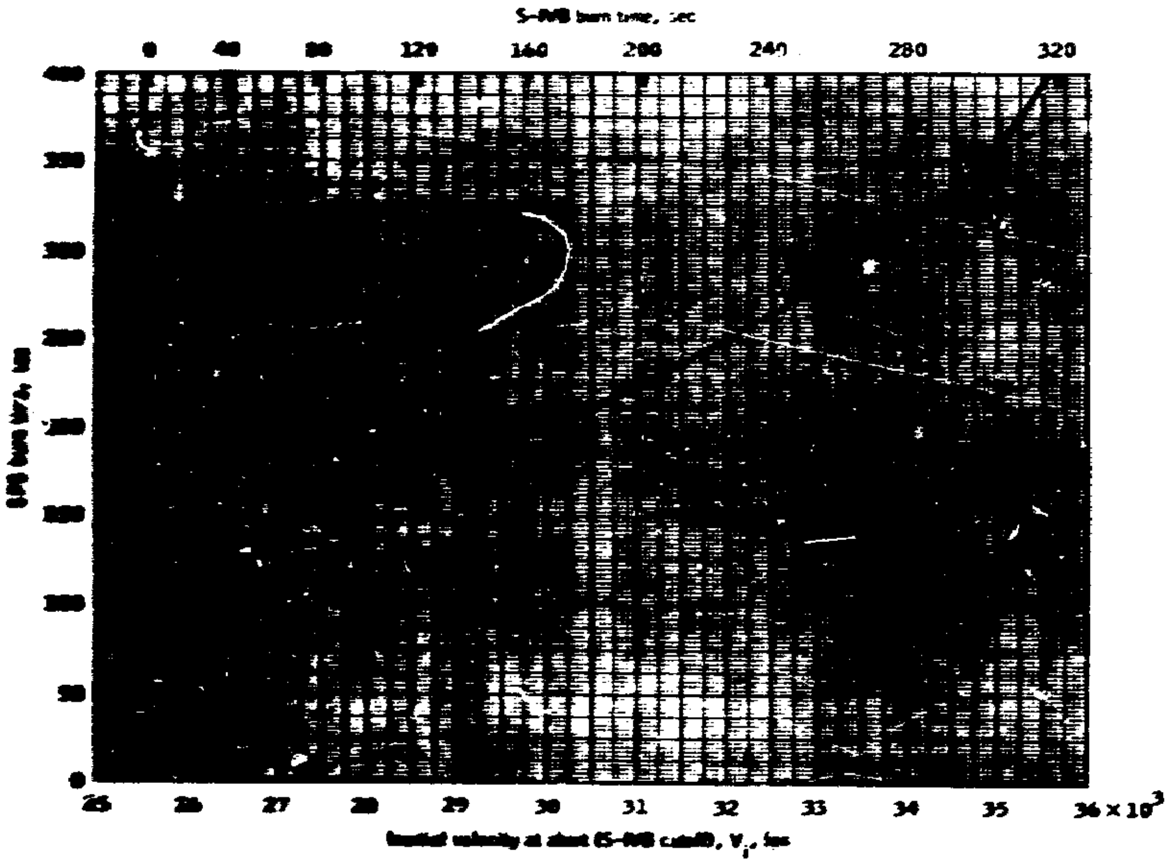


Figure 7-11.- SPS burn time as a function of inertial velocity at abort.

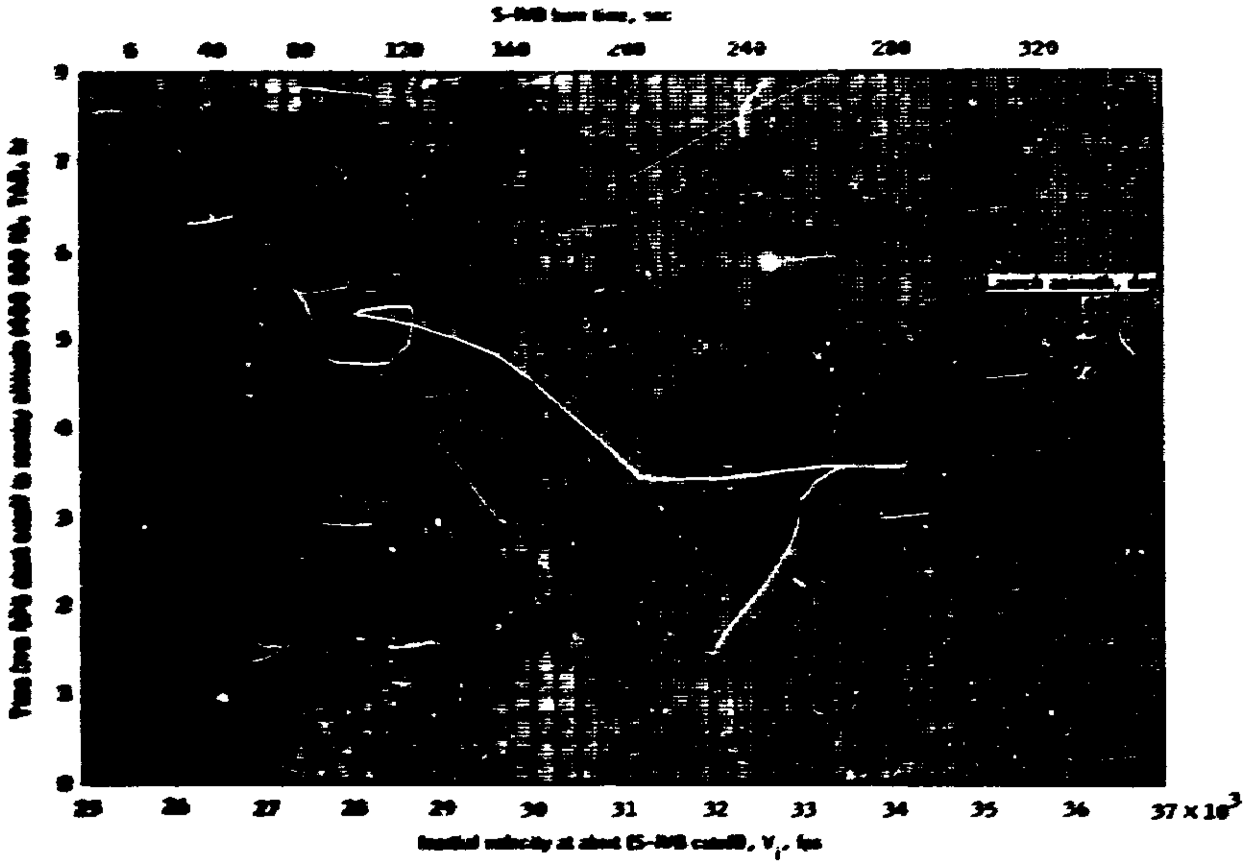
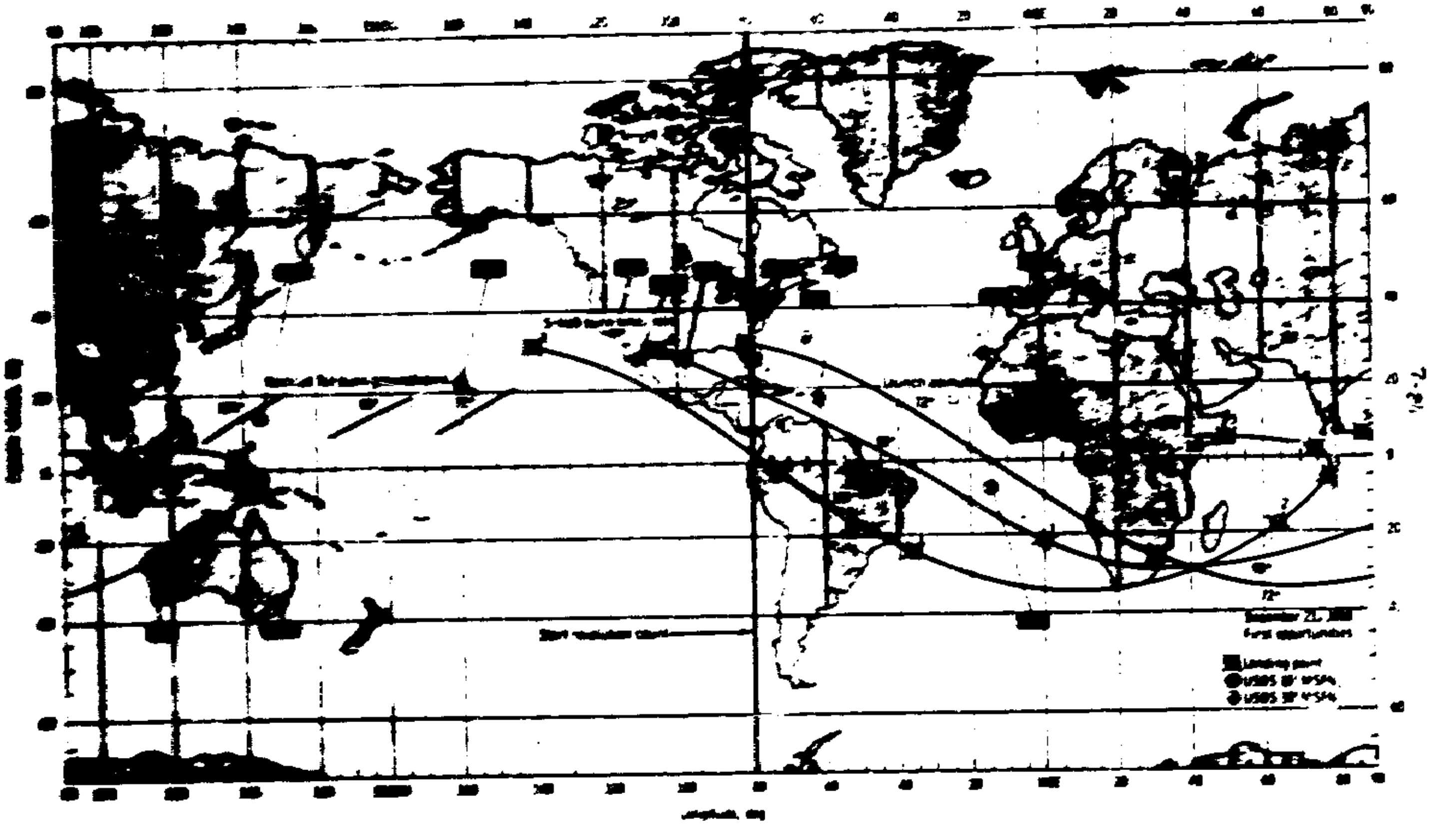
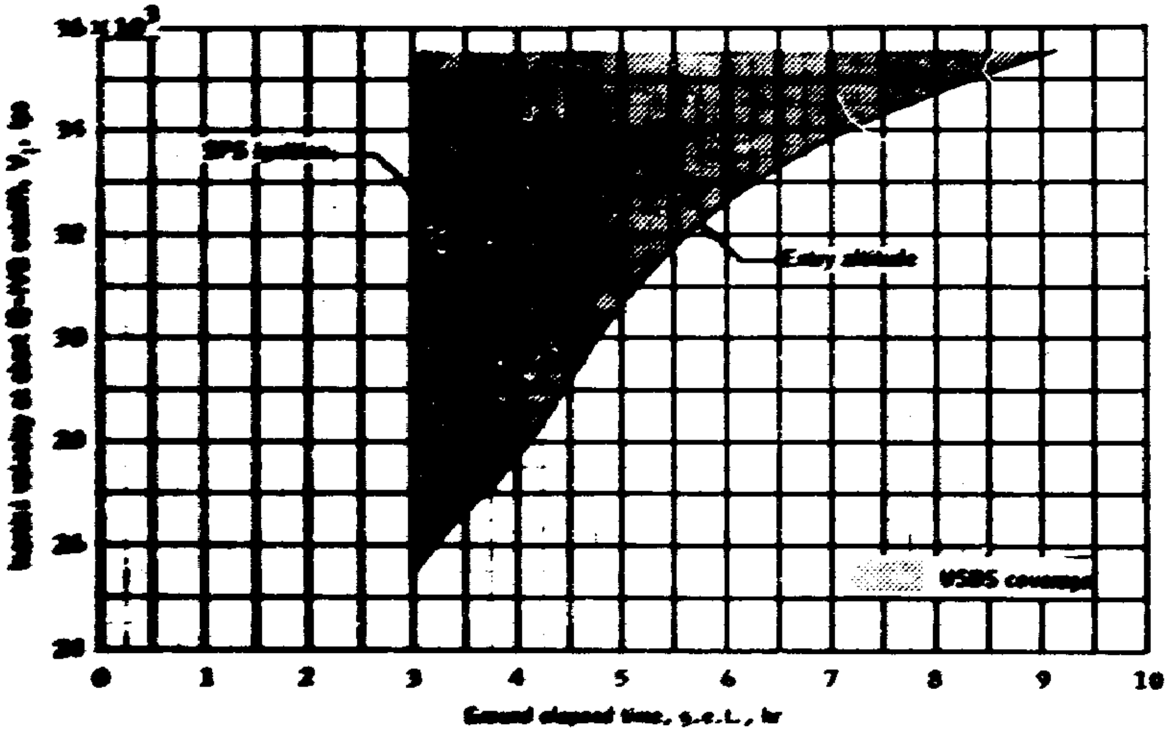


Figure 7-32.- Time from SPS cutoff to 400 000 feet as a function of inertial velocity at abort for fixed-attitude aborts from TLI.

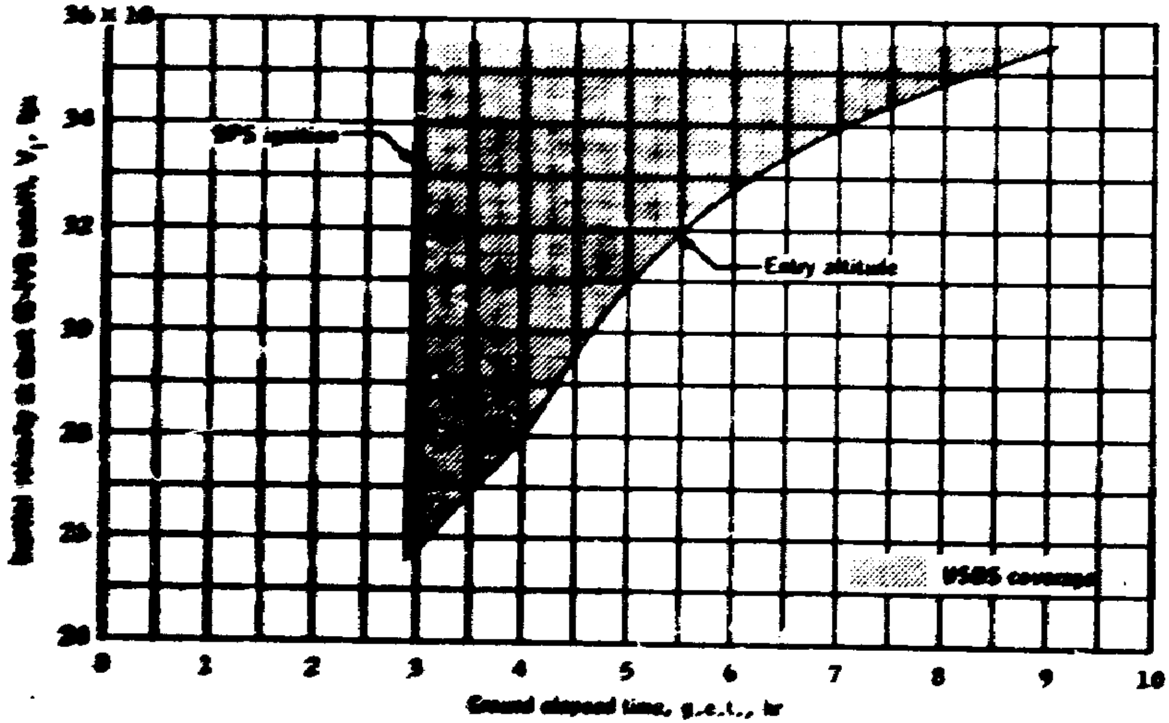


[illegible] landing point loci.



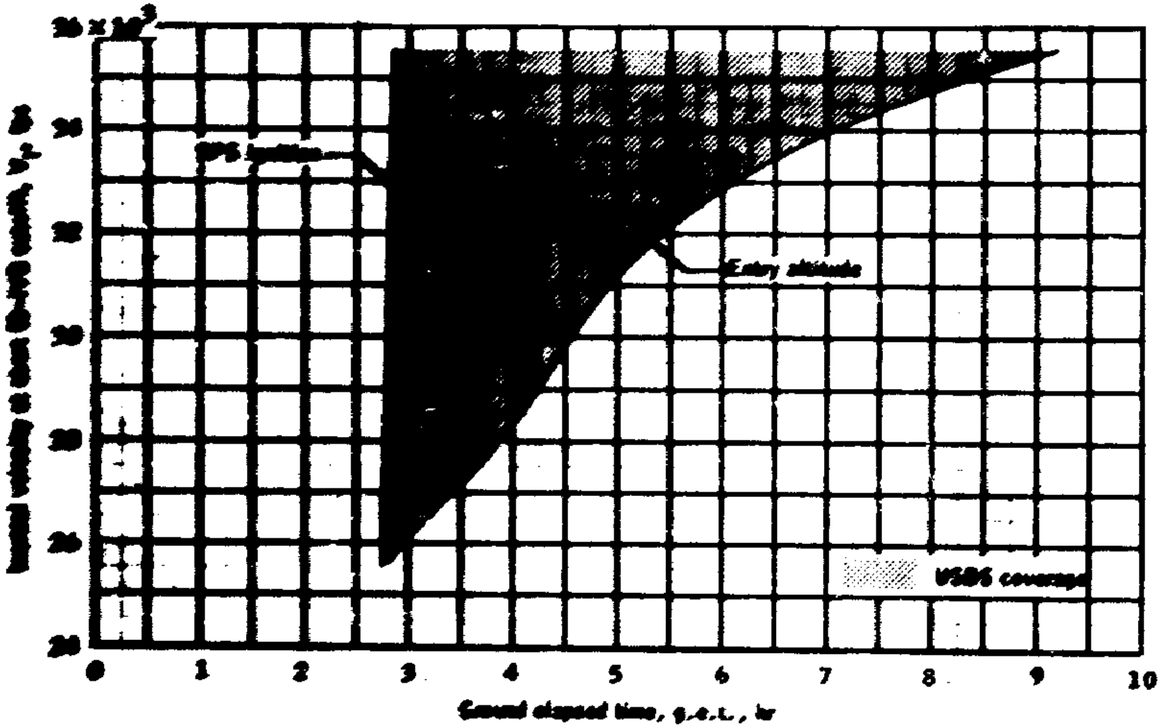
(a) Launch azimuth = 72°, first opportunity.

Figure 7-24.- Ground elapsed time of continuous VSBS coverage for fixed-attitude aborts from TLI as a function of inertial velocity at abort.



(b) Launch azimuth = 90°, first opportunity.

Figure 7-14.- Continued.



(c) Launch azimuth = 108°, first opportunity.

Figure 7-14.- Concluded.

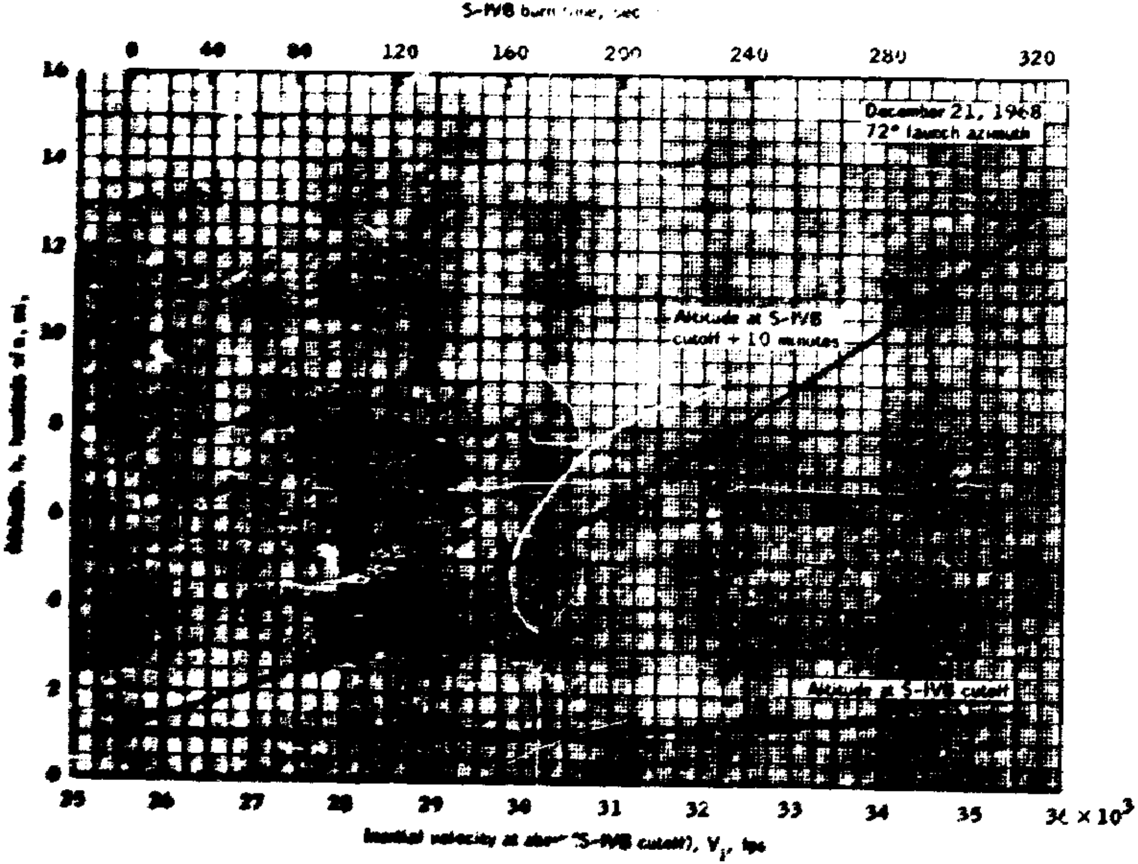


Figure 7-15.- Altitude at S-IVB cutoff and altitude at S-IVB cutoff-plus-10-minutes as functions of inertial velocity at abort for fixed-attitude aborts.

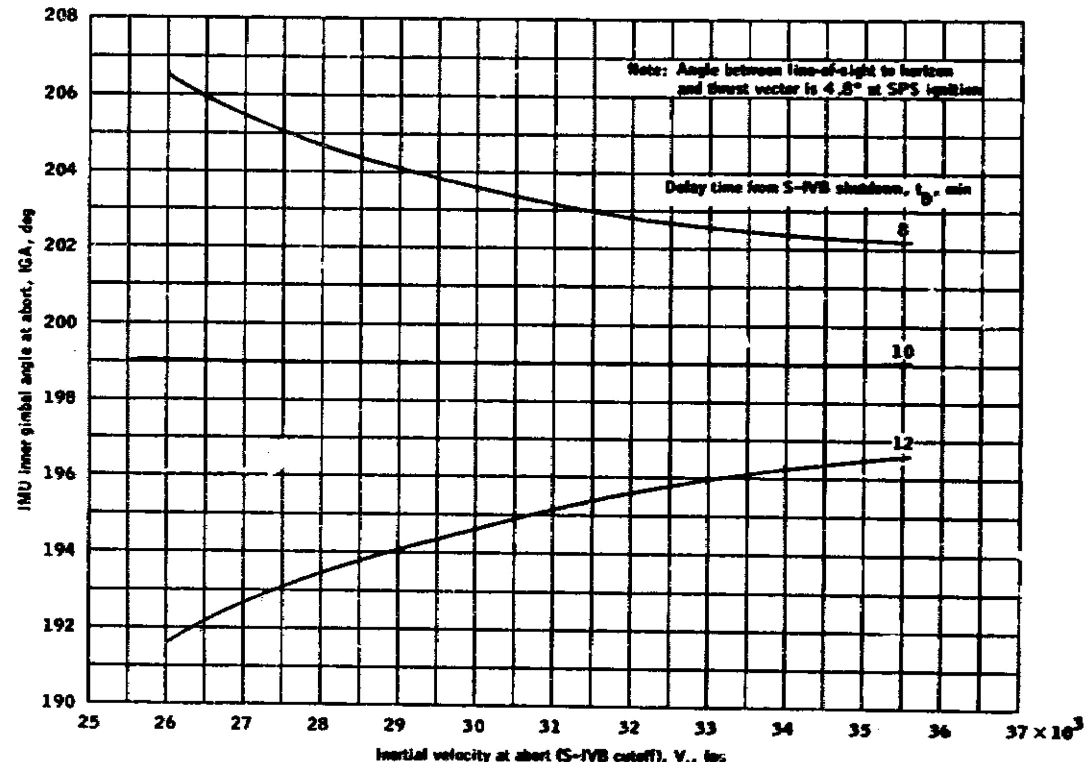


Figure 7-16.- Required IMU inner gimbal angle for fixed-attitude horizon reference aborts at various delay times from S-IVB cutoff as a function of inertial velocity at abort.

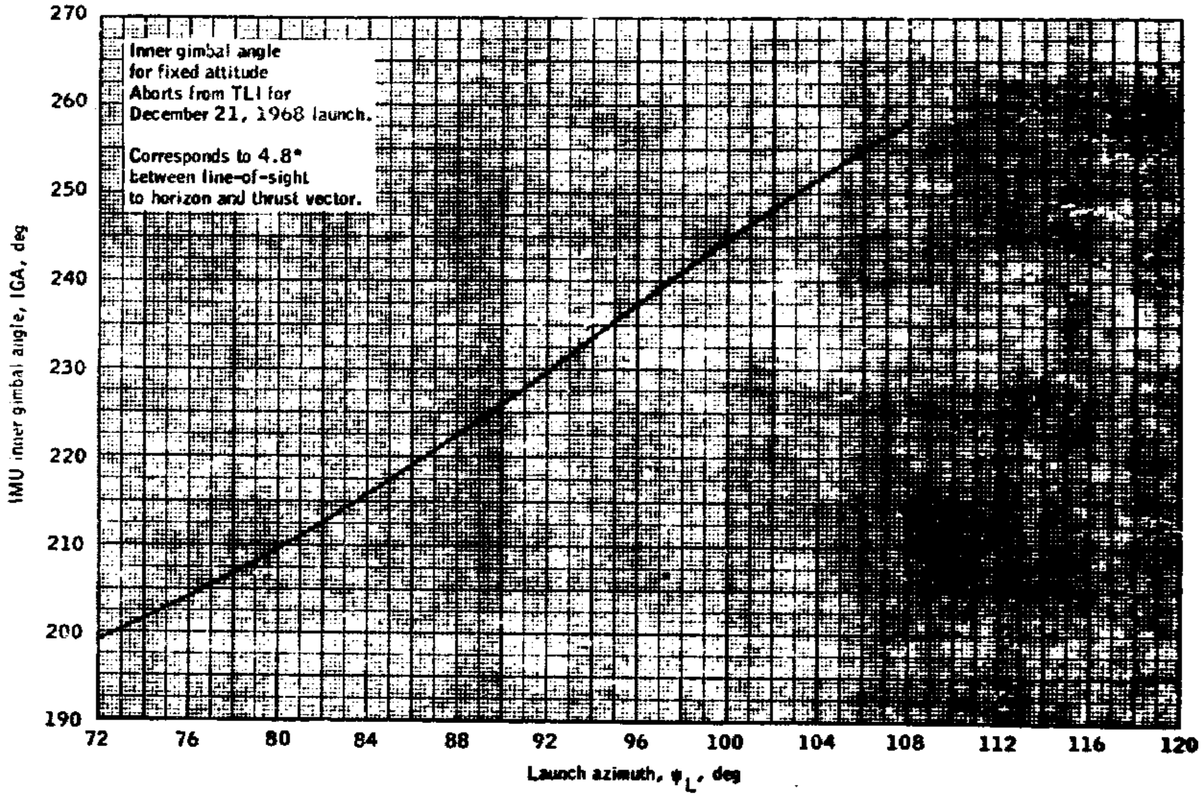


Figure 7-17.- Inner gimbal angle at S-IVB cutoff-plus-10-minutes as a function of launch azimuth.

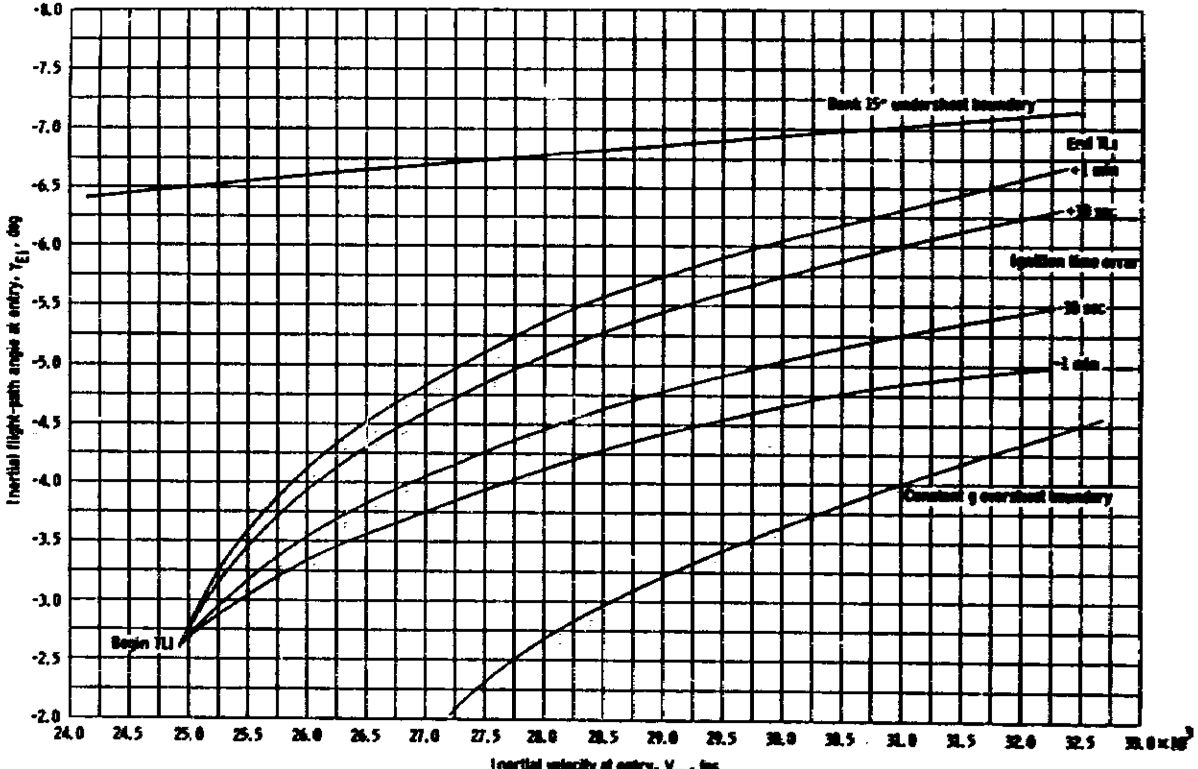


Figure 7-18. - Effect of ignition time errors on entry conditions for fixed attitude aborts from TLI assuming the abort ΔV required at TLI cutoff-plus-10-minutes is applied at the horizon reference attitude required at TLI-plus-10-minutes.

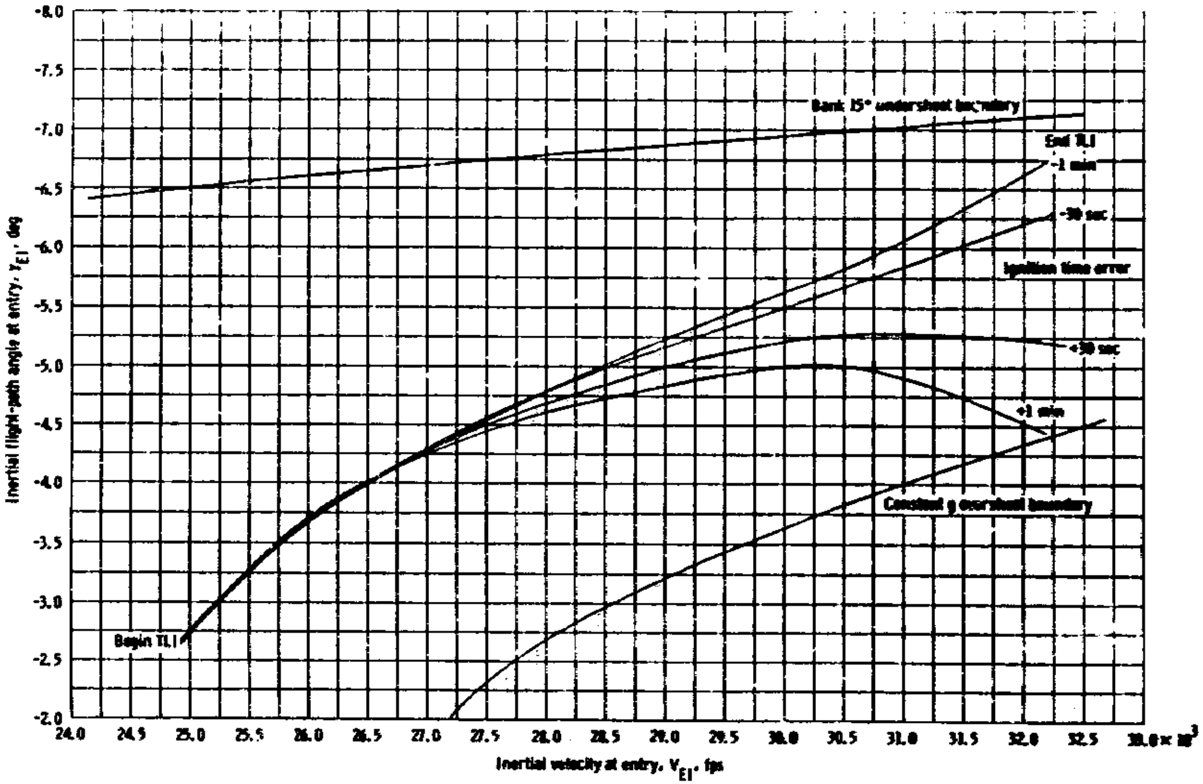


Figure 7-19.- Effect of ignition time errors on entry conditions for fixed attitude aborts from TLI assuming the abort ΔV required at TLI cutoff-plus-10-minutes is applied at the inertial attitude required at TLI-plus-10-minutes.

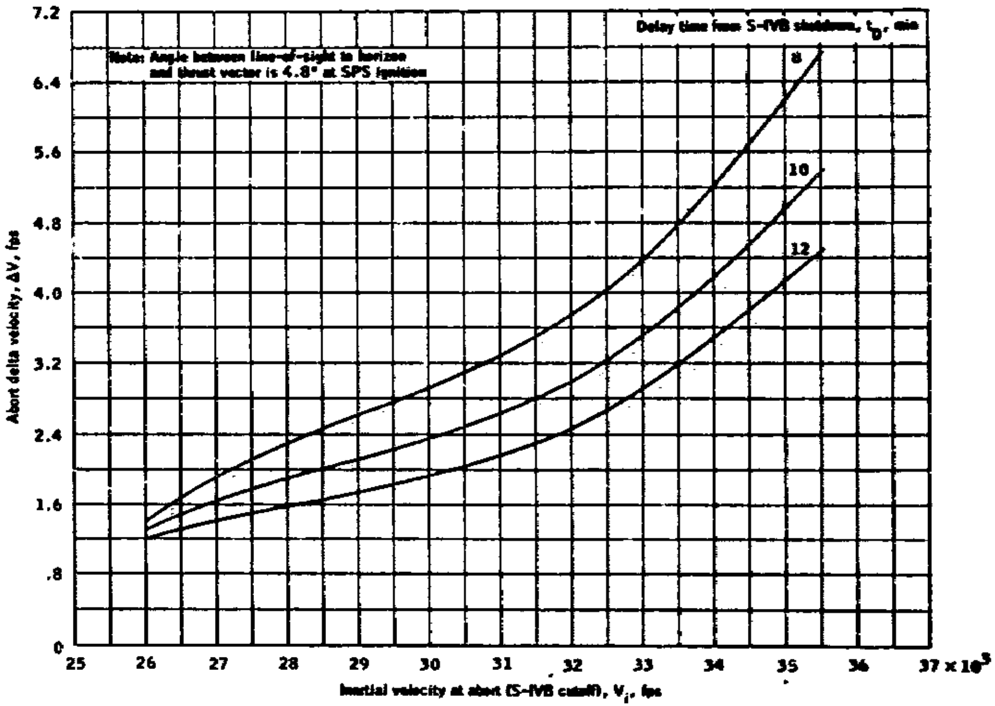


Figure 7-20.- Required abort ΔV for fixed attitude horizon reference aborts at various delay times from S-IVB cutoff as a function of inertial velocity at abort.

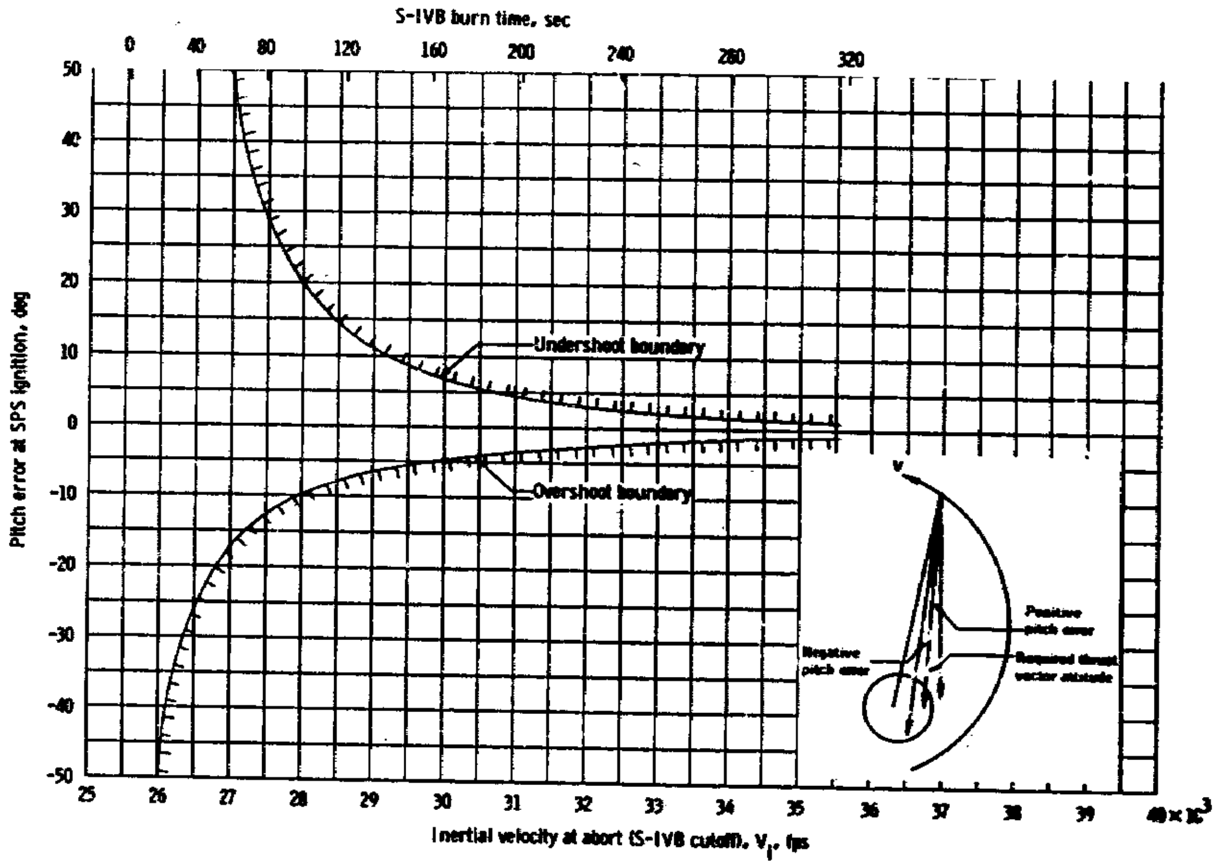


Figure 7-21. - Tolerable pitch errors for the fixed attitude aborts from TLI as a function of inertial velocity at abort.

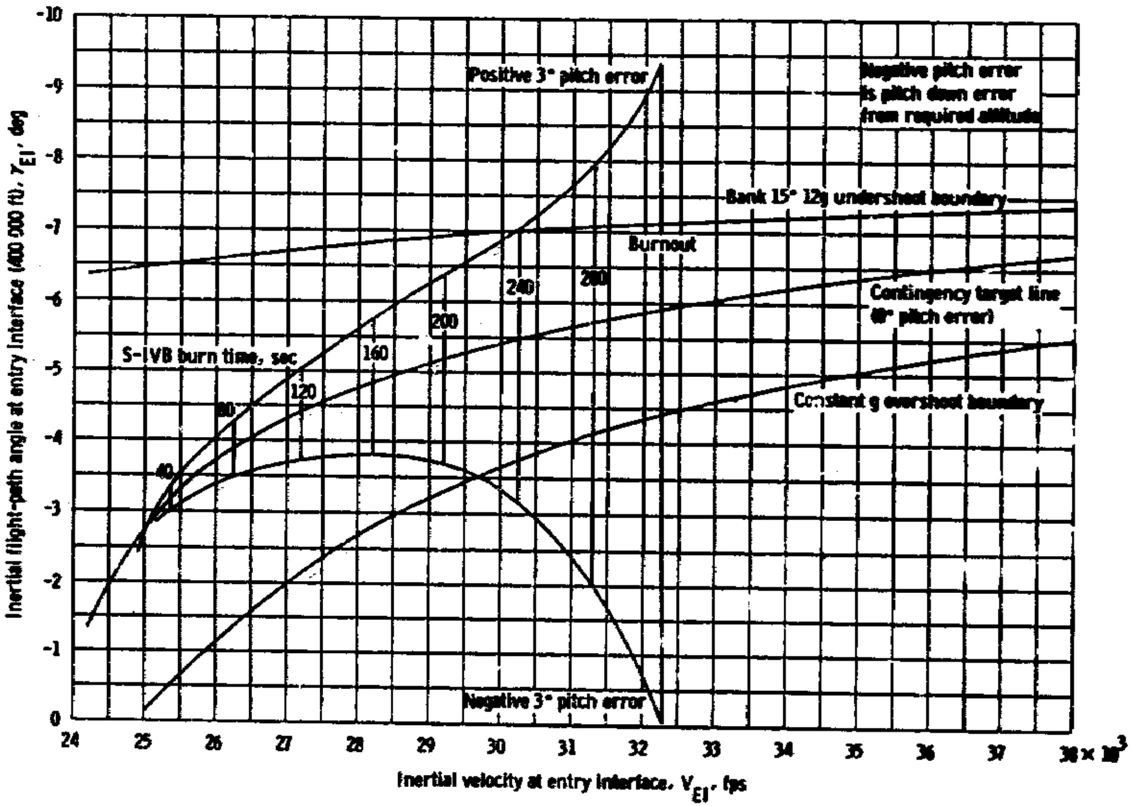
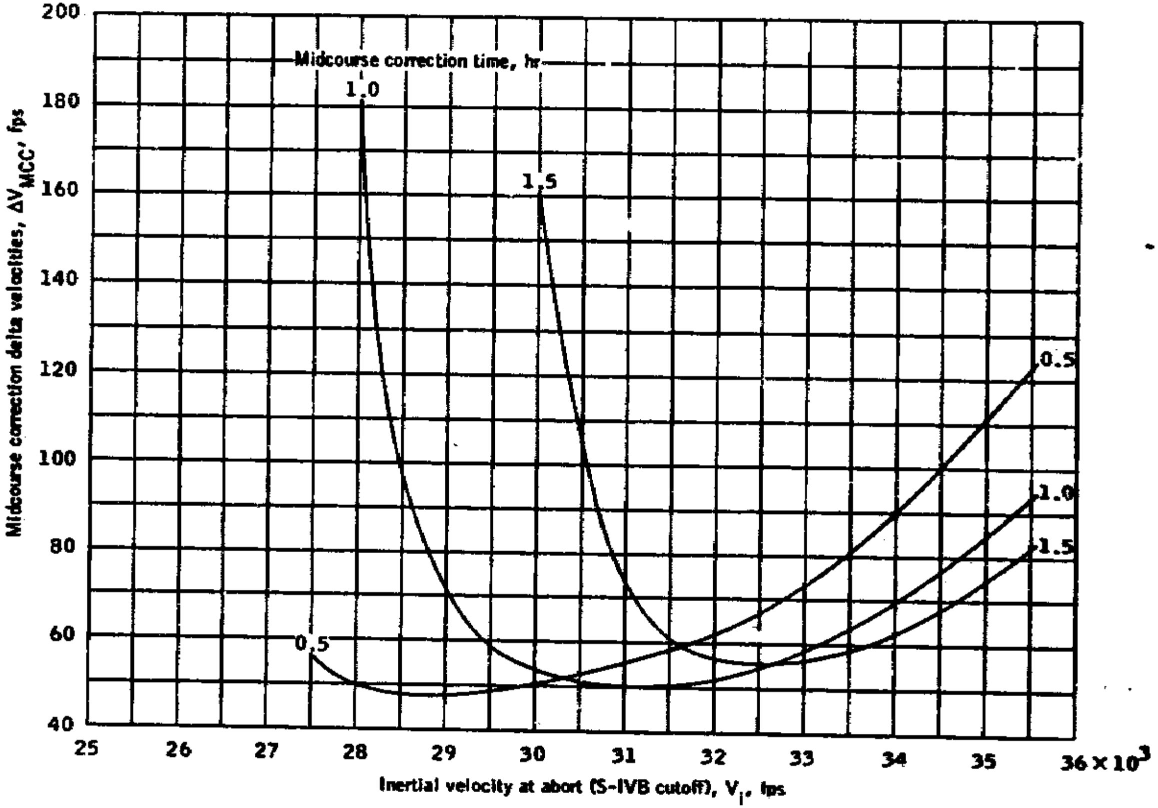
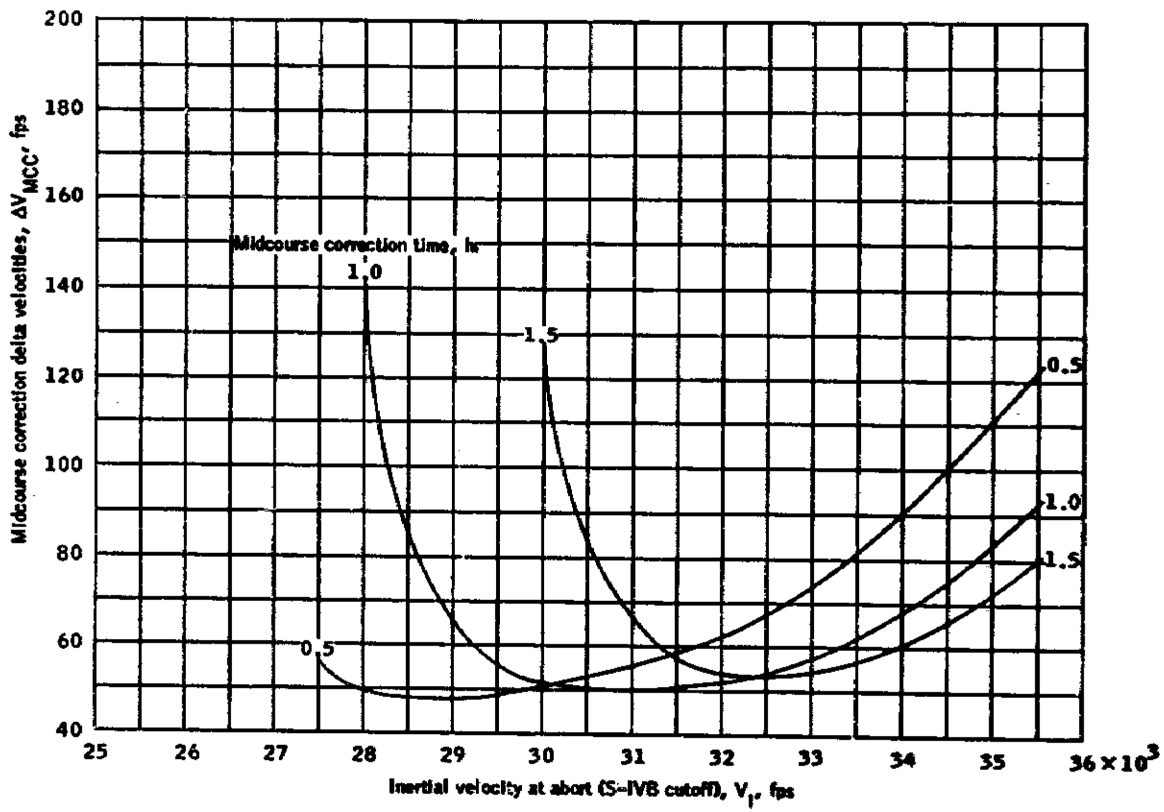


Figure 7-22. - Effect of positive and negative 3° pitch errors on entry vector for fixed-attitude aborts from TLI.



(a) +3° pitch error.

Figure 7-23.- Midcourse correction delta velocities required at various delay times to achieve the contingency target line.



(b) -3° pitch error.

Figure 7-23.- Concluded.

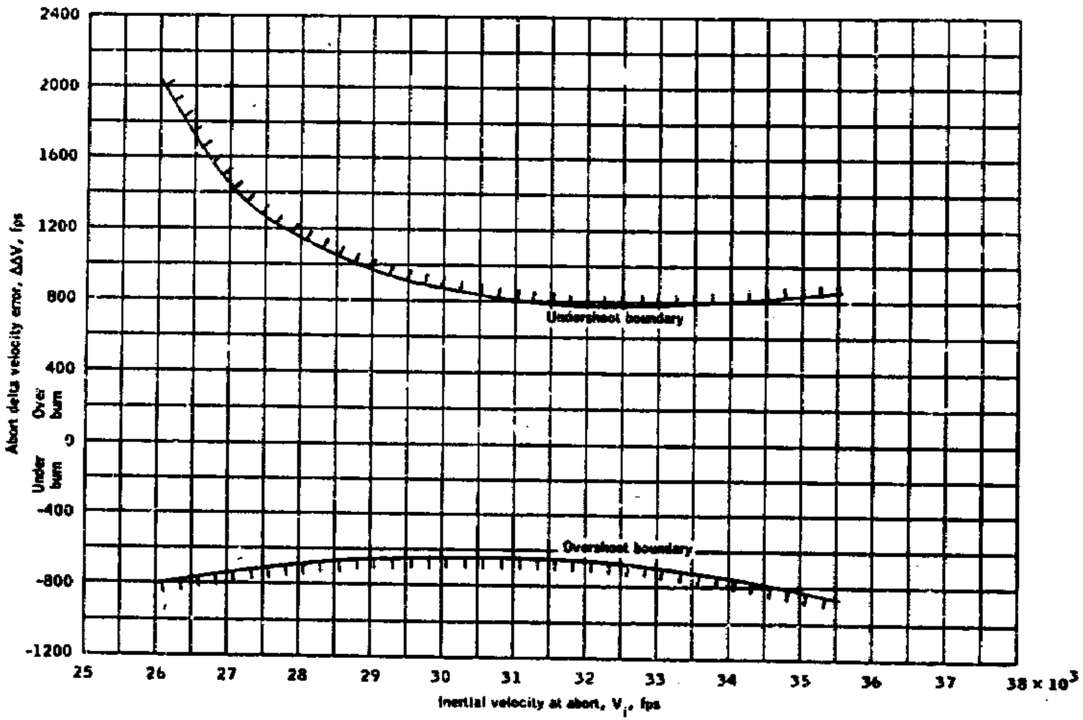


Figure 7-24.- Abort delta velocity error required to achieve overshoot and undershoot reentry boundaries for fixed-attitude abort maneuvers from TLI.

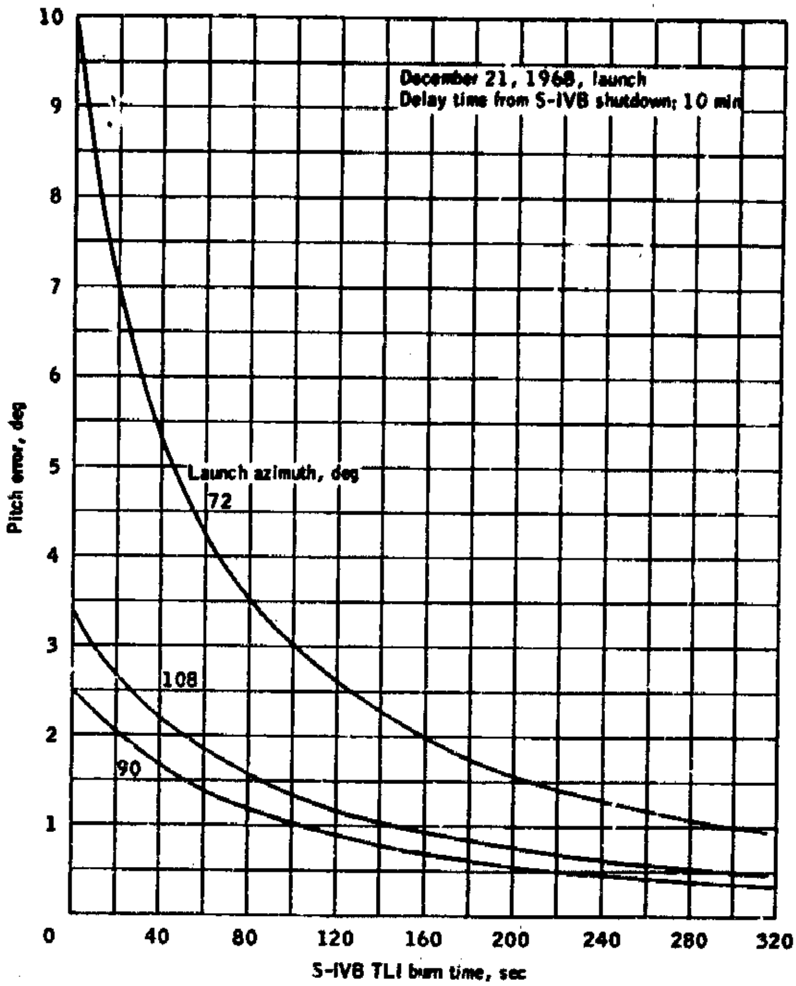


Figure 7-25.- Pitch pointing error that could result from aligning relative to a terminator mistaken for the inplane far horizon.

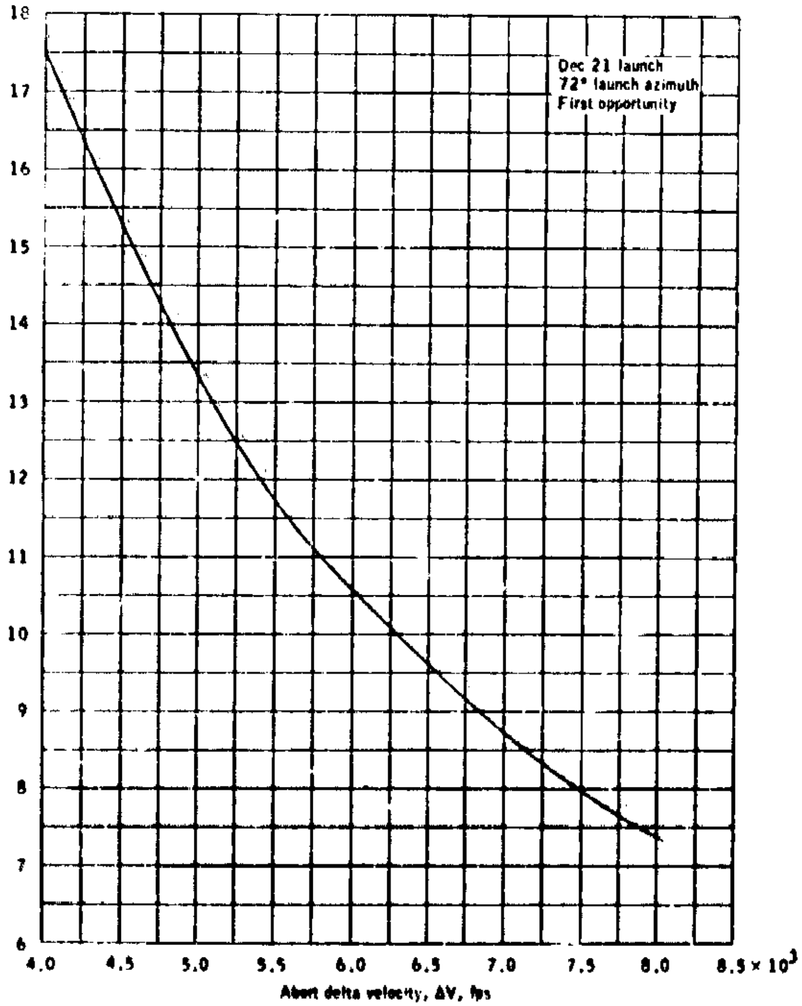
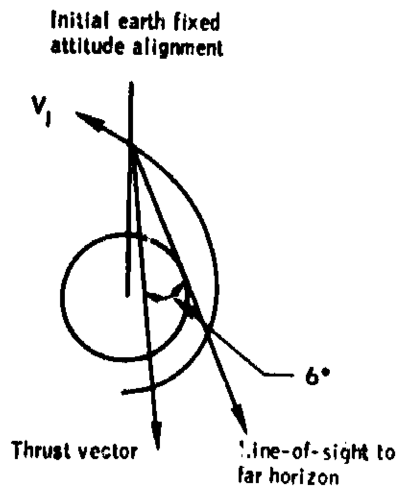


Figure 7-26.- Time from abort (SPS cutoff) to reentry (400 000 ft altitude) as a function of abort ΔV for the abort at TLI cutoff-plus-90-minutes (impulsive point).



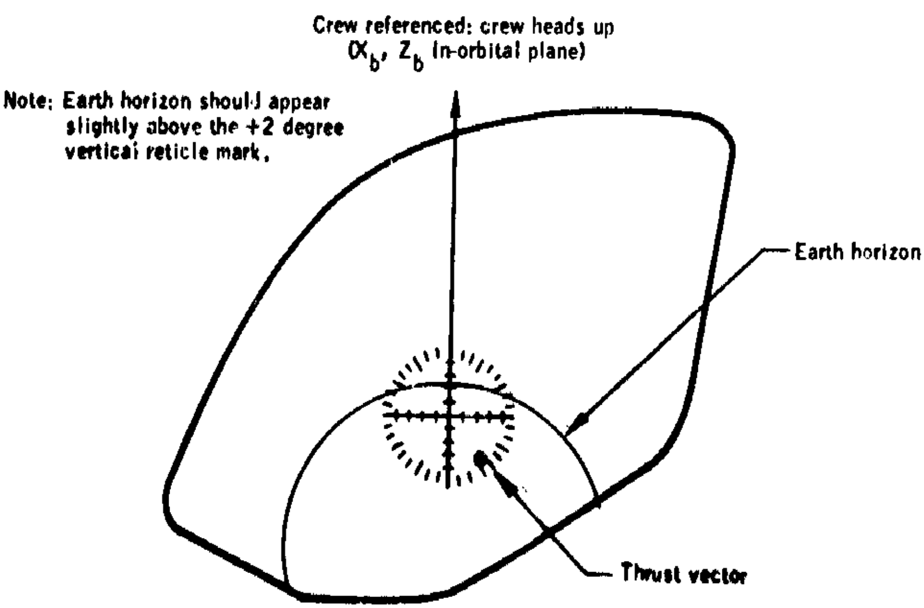


Figure 7-27.- Definition of attitude for TLI-plus-90-minute aborts.

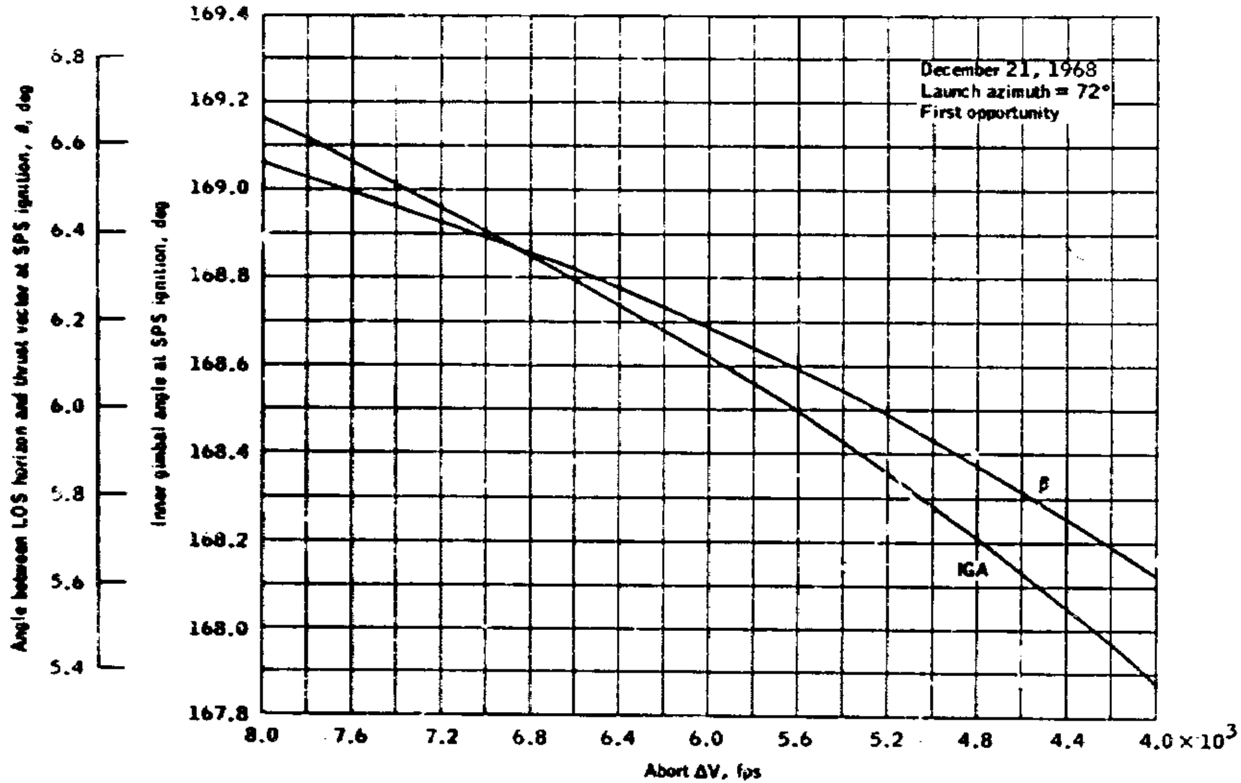


Figure 7-28.- IMU inner gimbal angle and the angle between line of sight to the horizon and the thrust vector at SPS ignition for the TLI-plus-90-minute abort as functions of abort ΔV.

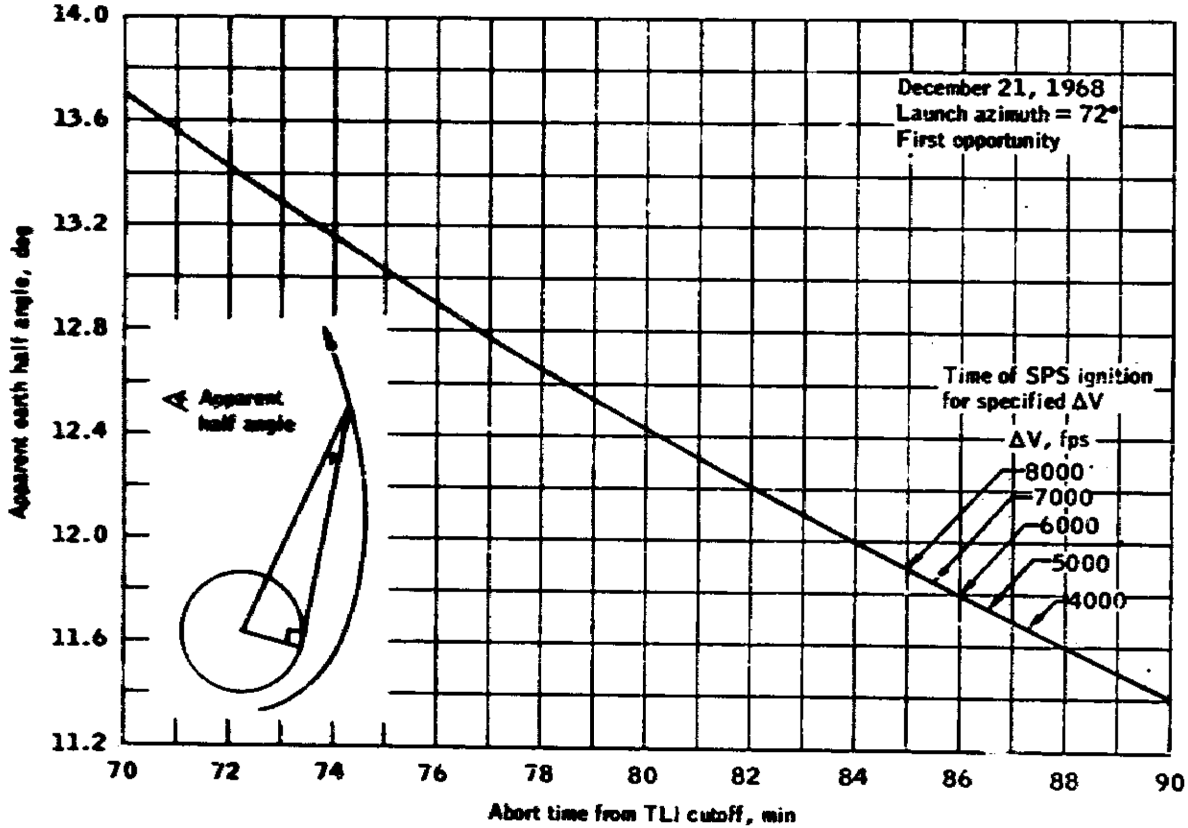


Figure 7-29.- Apparent half angle of the earth as a function of time from TLI cutoff.

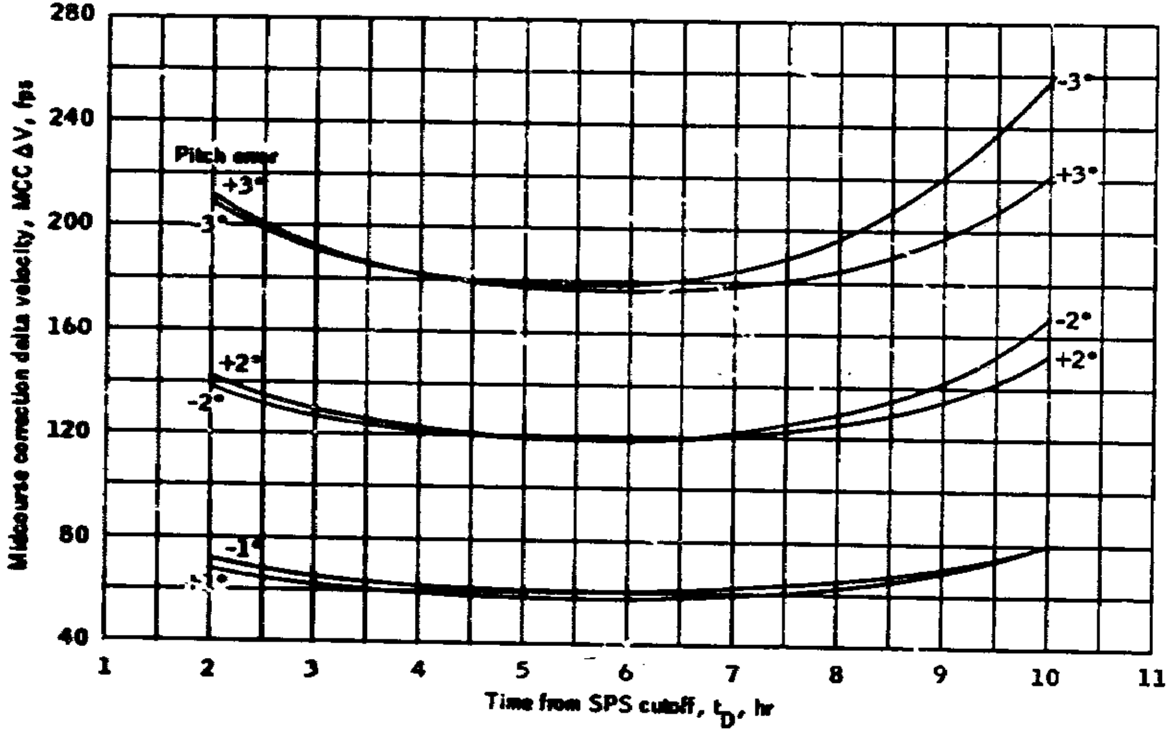


Figure 7-30.- Midcourse correction delta velocities for various pitch pointing errors required to achieve the contingency target line as a function of time from SPS cutoff.

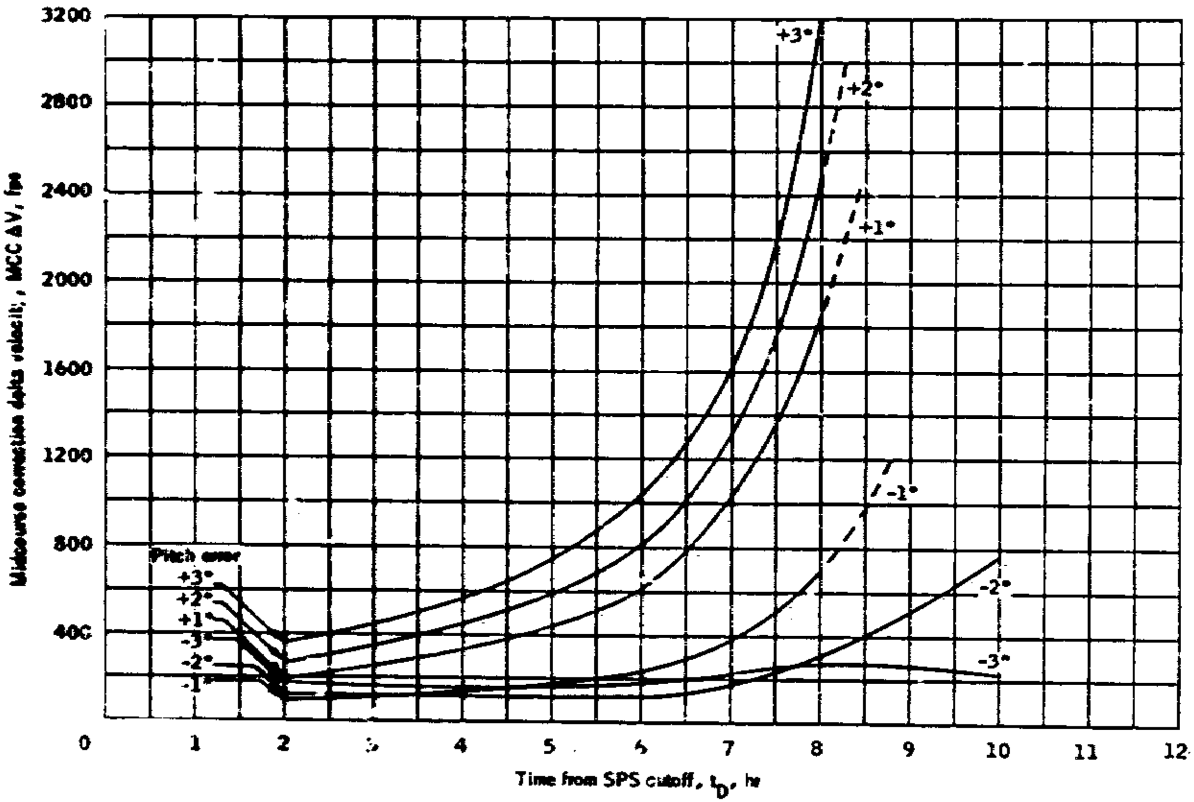


Figure 7-31.- Midcourse correction delta velocities for various pitch pointing errors required to achieve the contingency target line and the Atlantic Ocean Line (AOL) as a function of time from SPS cutoff.

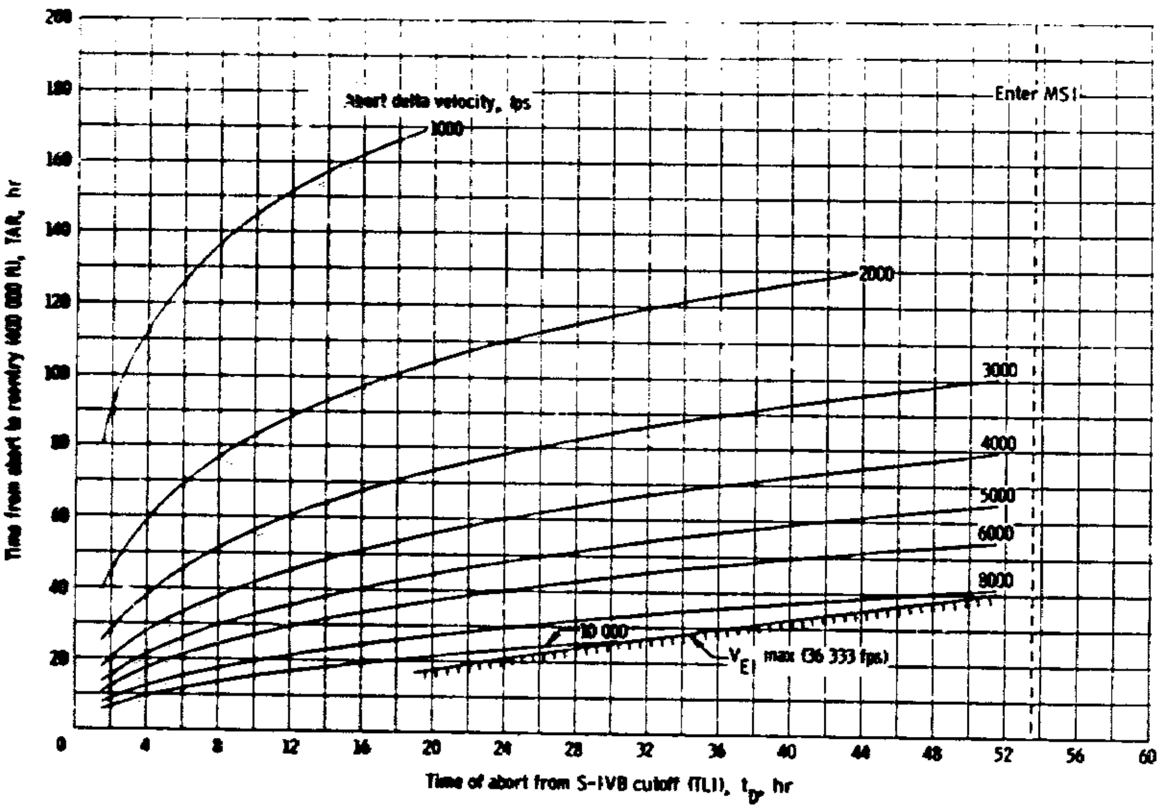


Figure 7-32. - Time from abort to reentry as a function of abort ΔV and delay time from S-IVB cutoff for unspecified area aborts from the nominal translunar coast. (December 21, 1968 launch, ψ_L = 72°, first opportunity.)

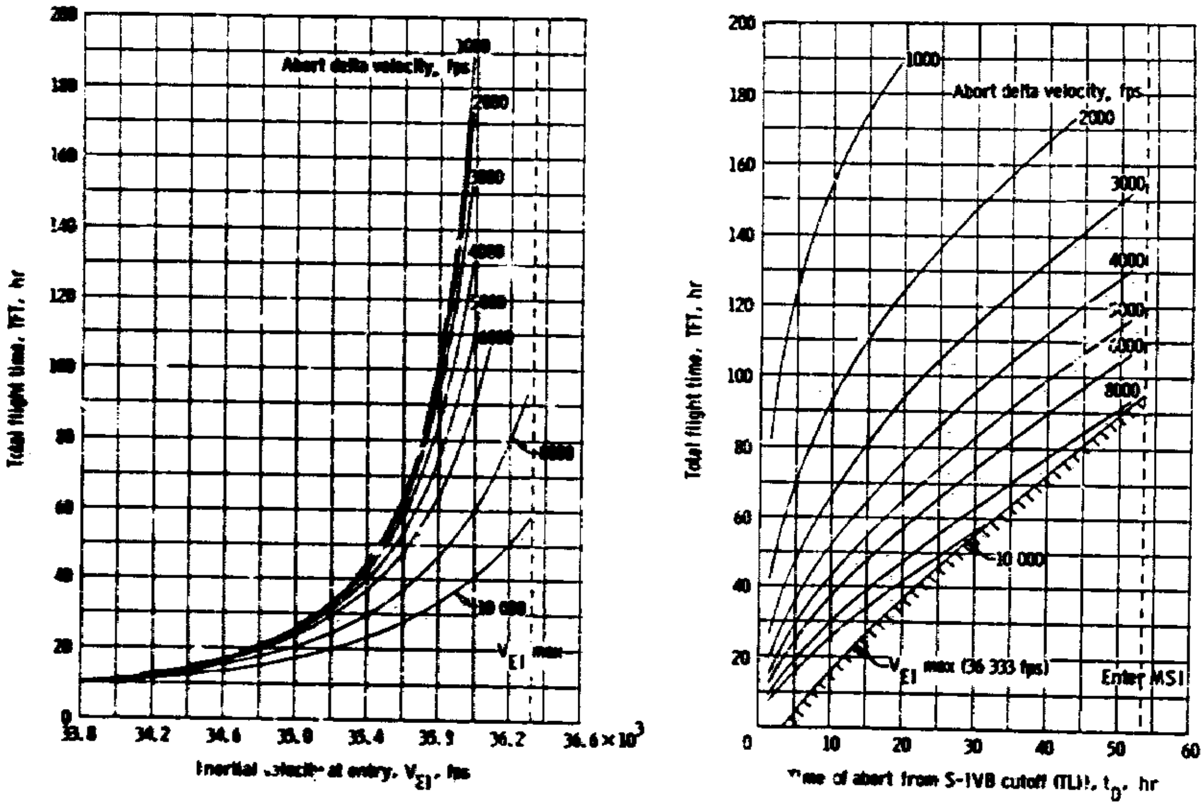


Figure 7-33.- Unspecified area abort analysis during nominal translunar coast. (December 21, 1968 launch, $\psi_L = 72°$, first opportunity.)

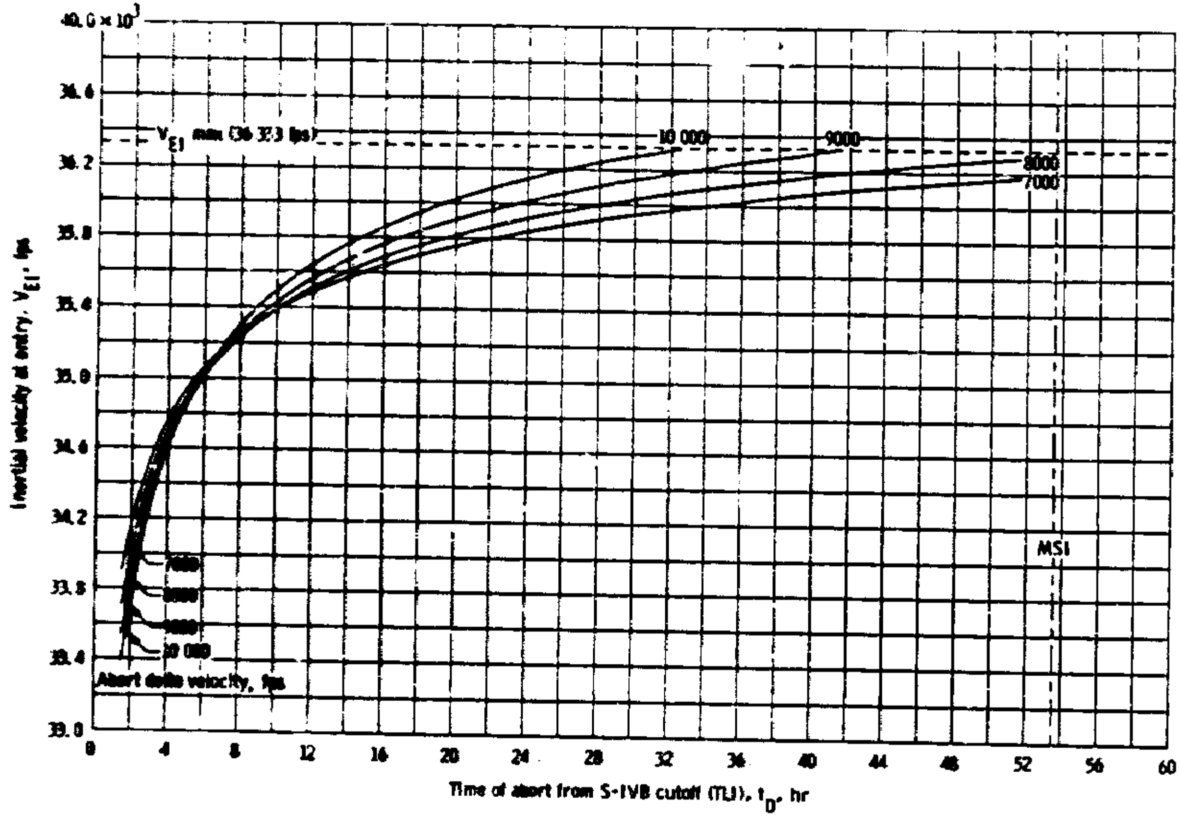
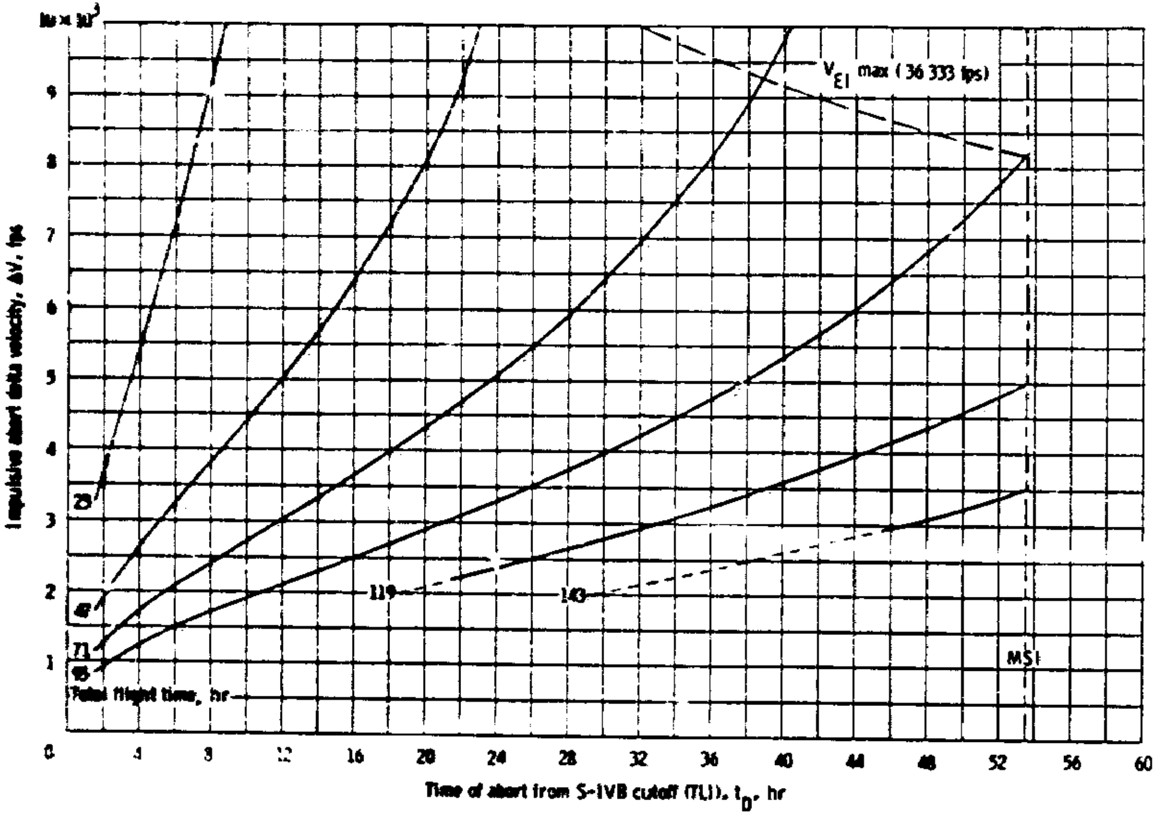
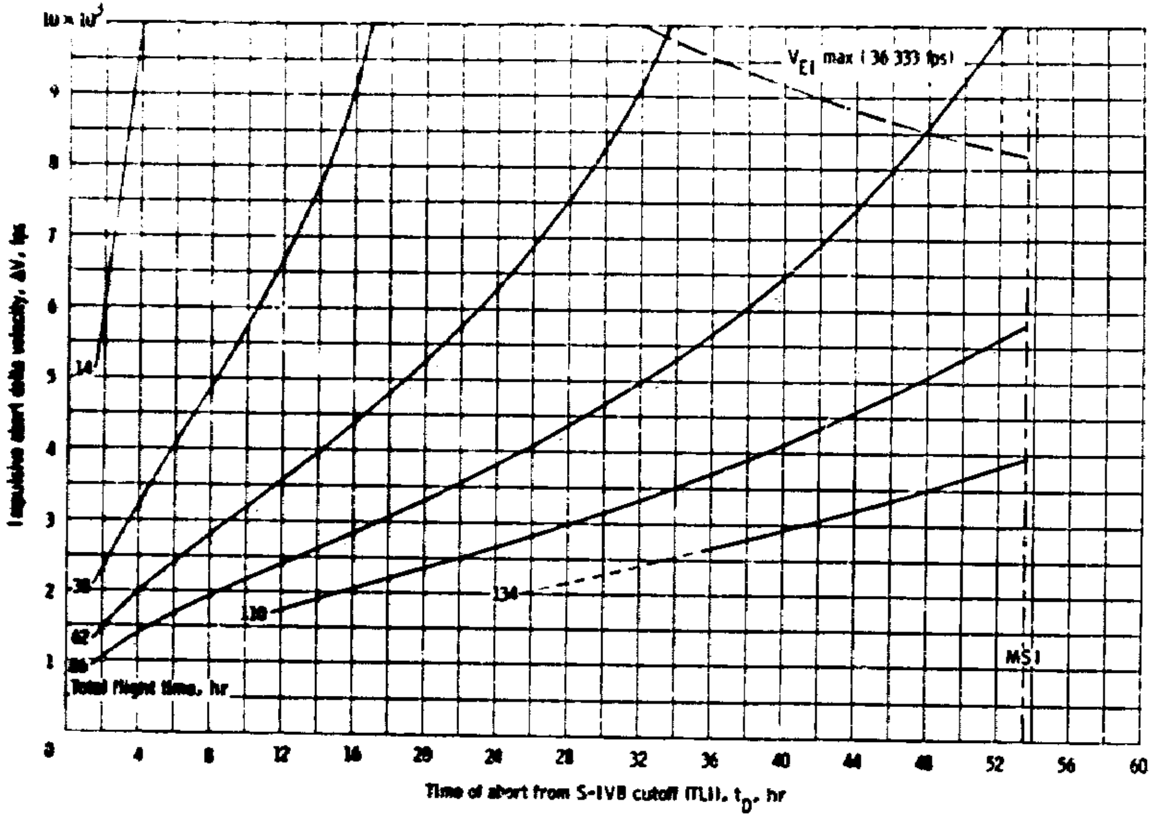


Figure 7-34. - Inertial velocity at entry as a function of time from S-IVB cutoff for unspecified area abort analysis.



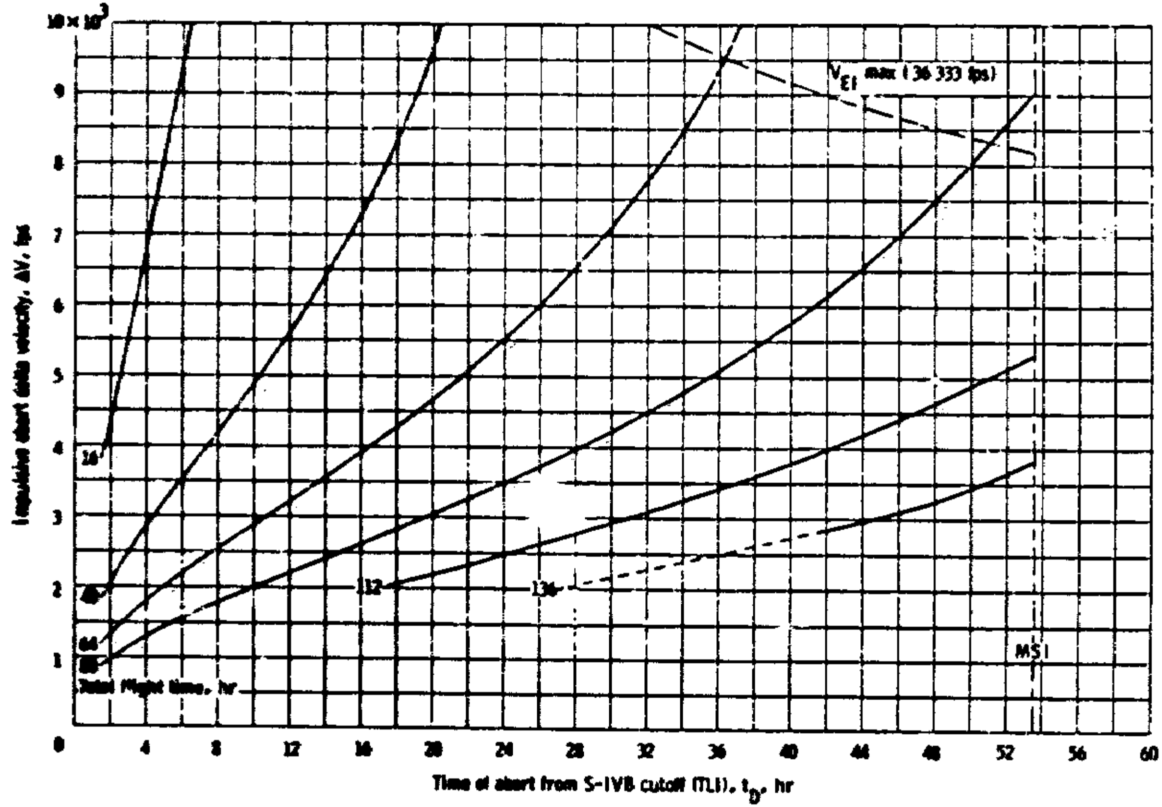
(a) MPL.

Figure 7-35. - Abort ΔV required to achieve total flight times to the contingency landing areas. (December 21, 1968 launch. First injection opportunity, $\psi_L = 72°$)



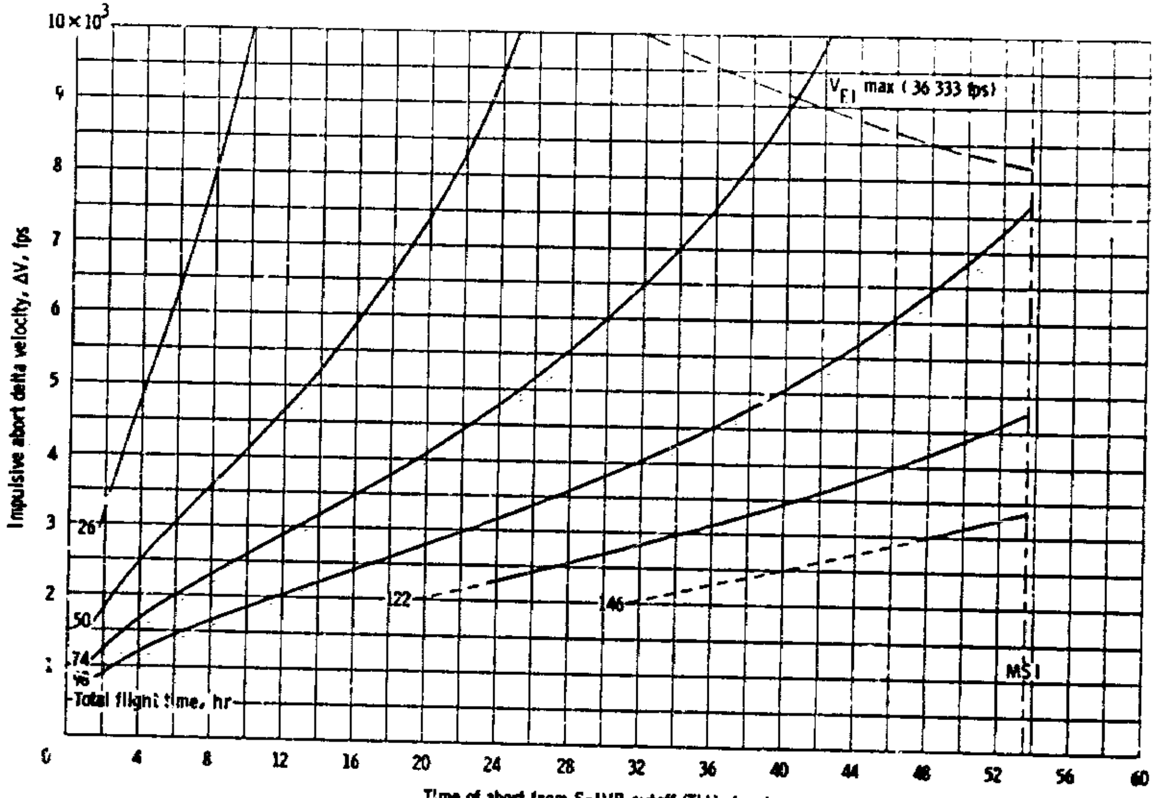
(b) AOL.

Figure 7-35.- Continued.



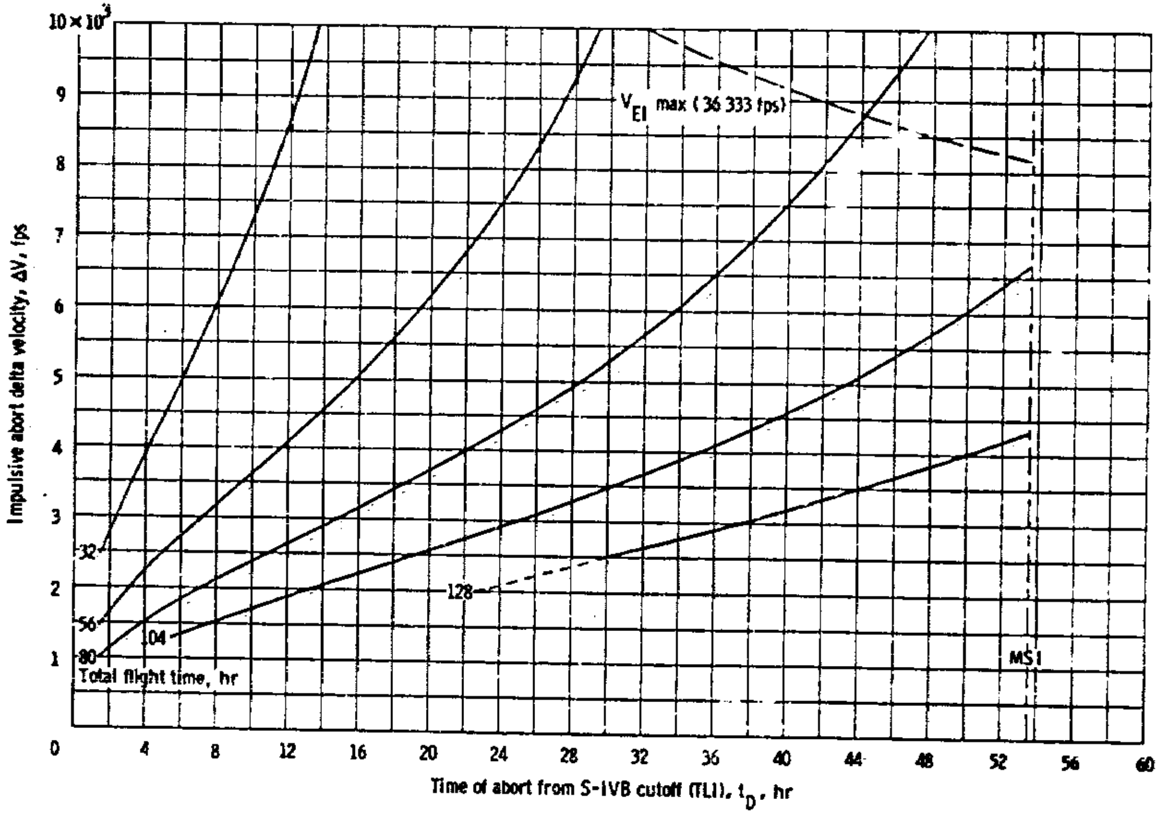
(c) EPL.

Figure 7-35. - Continued.



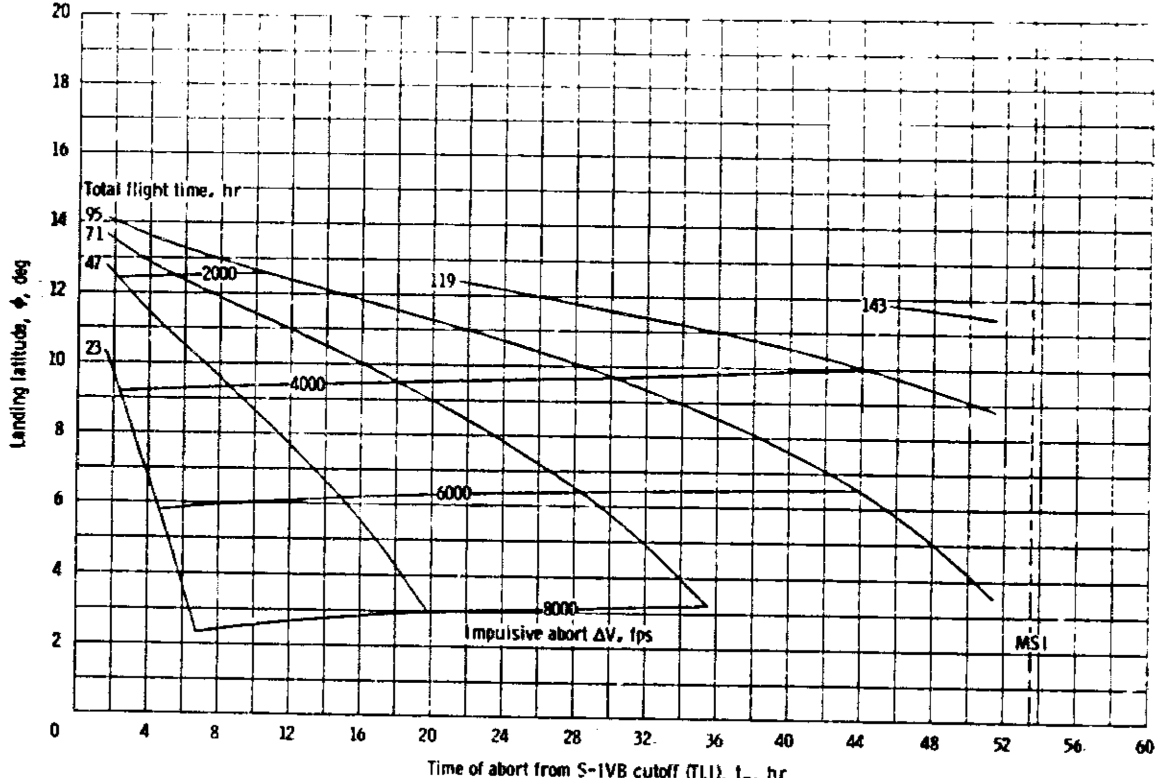
(d) WPL.

Figure 7-35. - Continued.



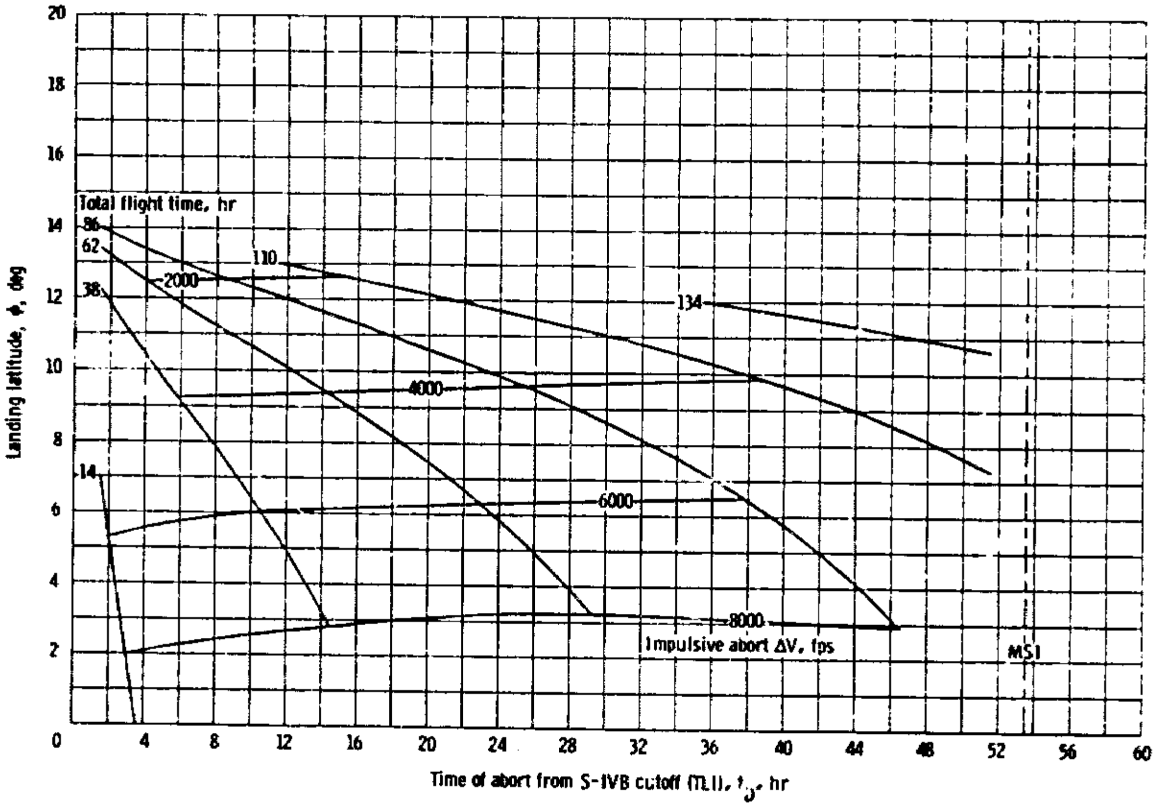
(e) I OL.

Figure 7-35. - Concluded.



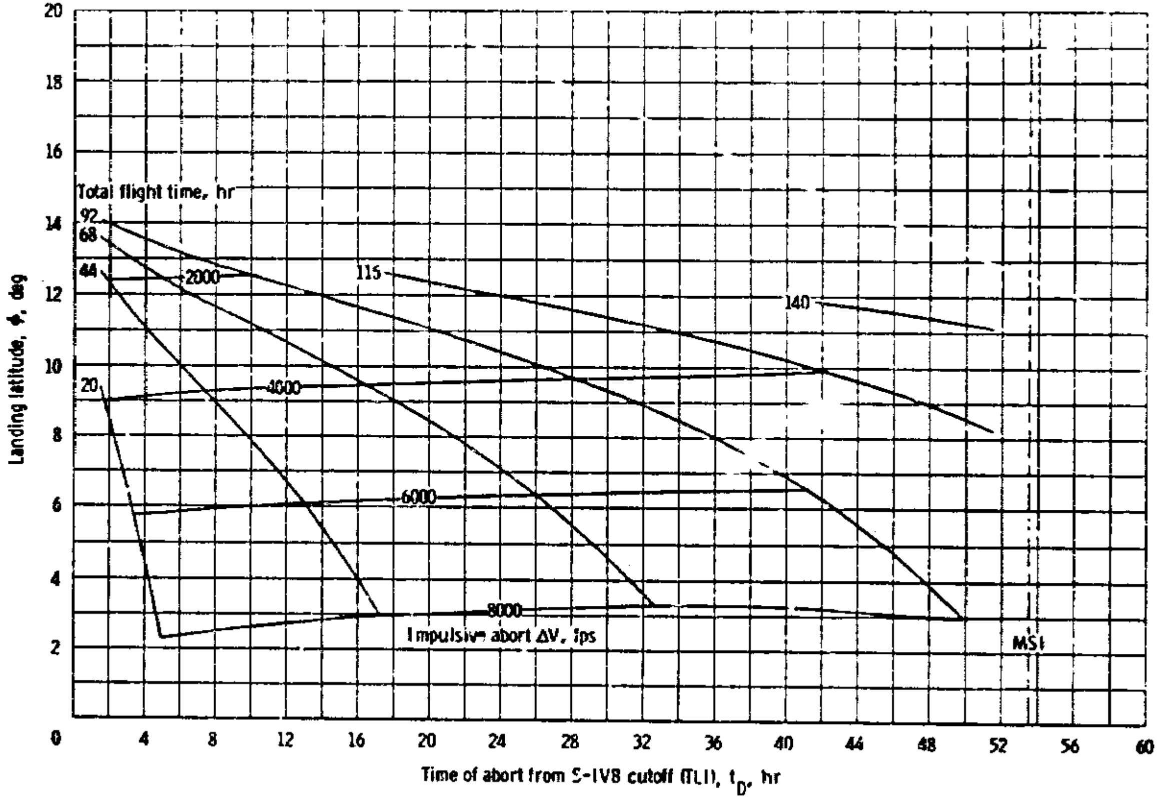
(a) MPL.

Figure 7-36. - Landing latitude as a function of abort ΔV and total flight time to the contingency landing areas. (December 21, 1968, launch. First injection opportunity, $\psi_L = 72°$.)



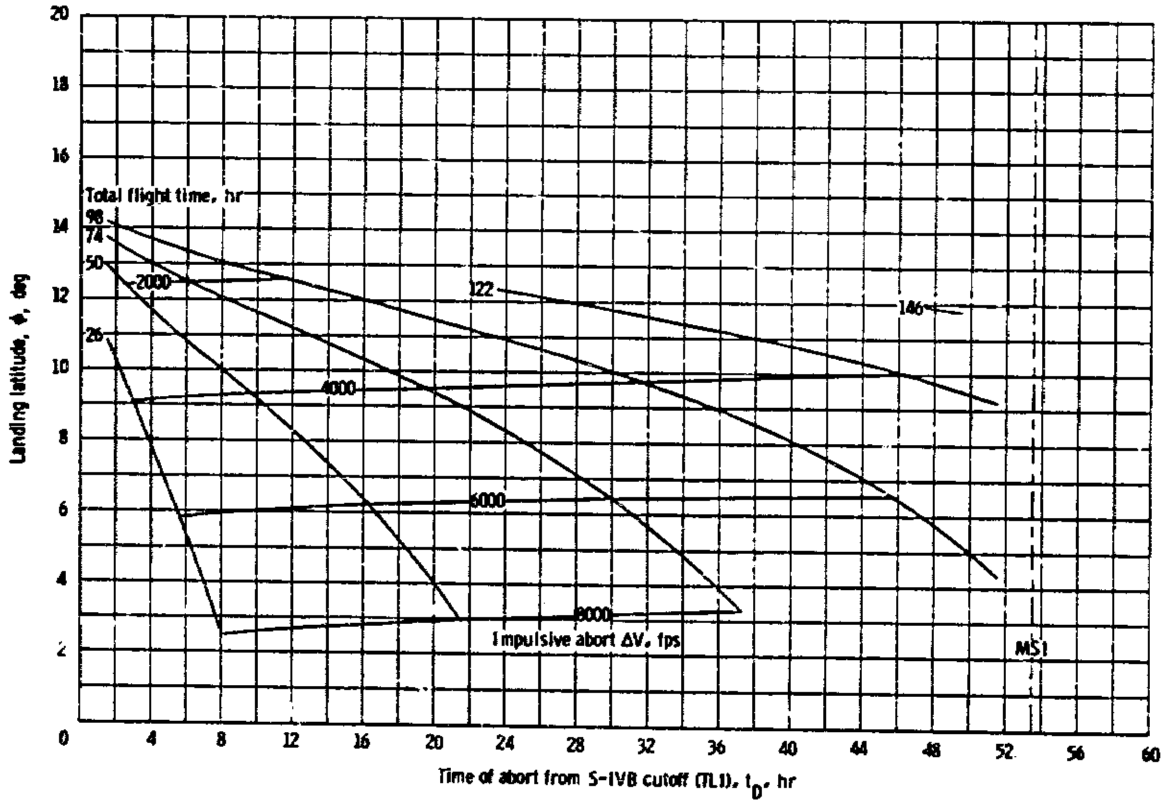
(b) AOL.

Figure 7-36. - Continued.



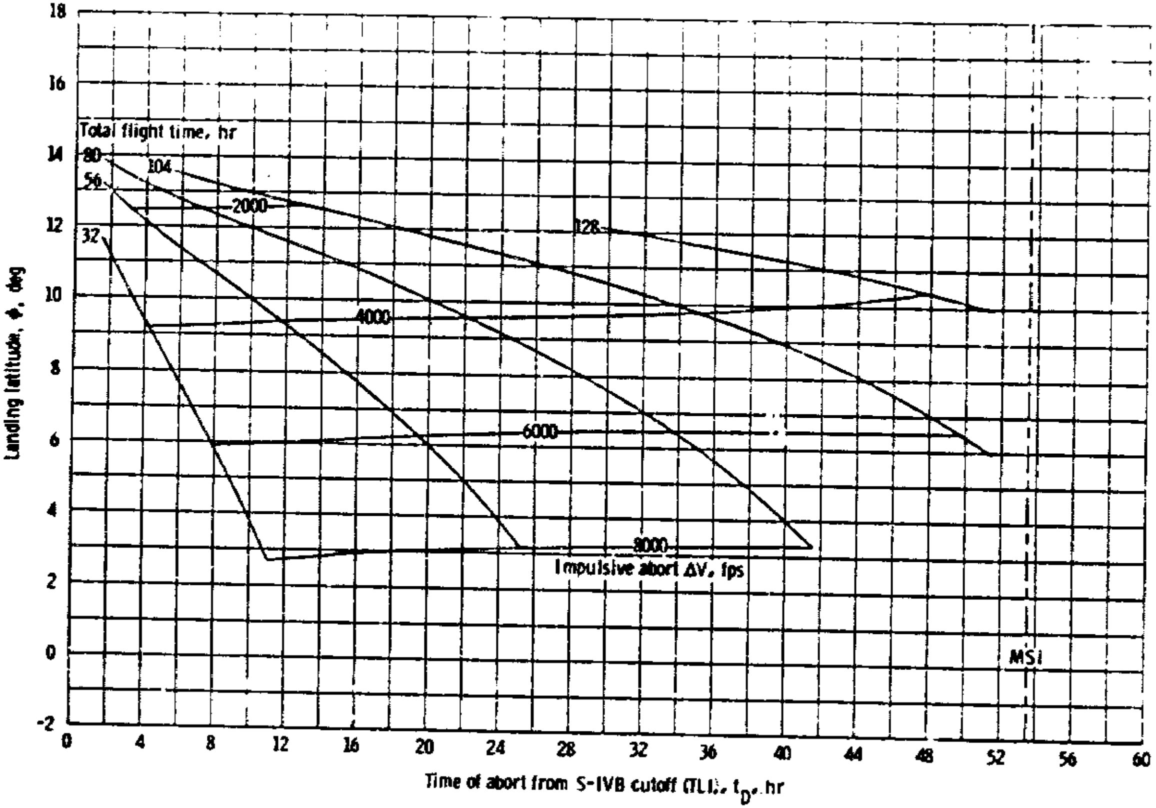
(c) EPL.

Figure 7-36. - Continued.



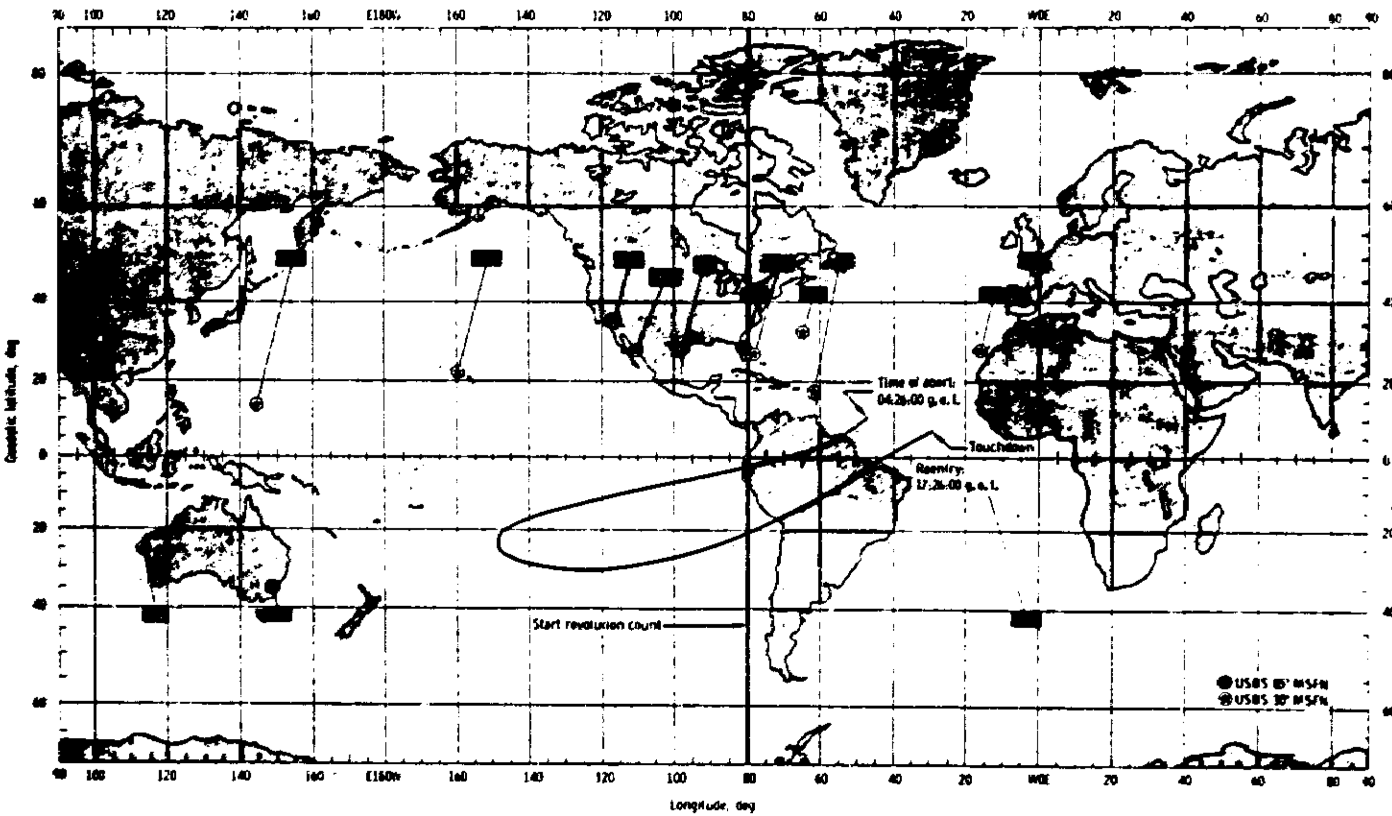
(d) WPL.

Figure 7-36. - Continued.



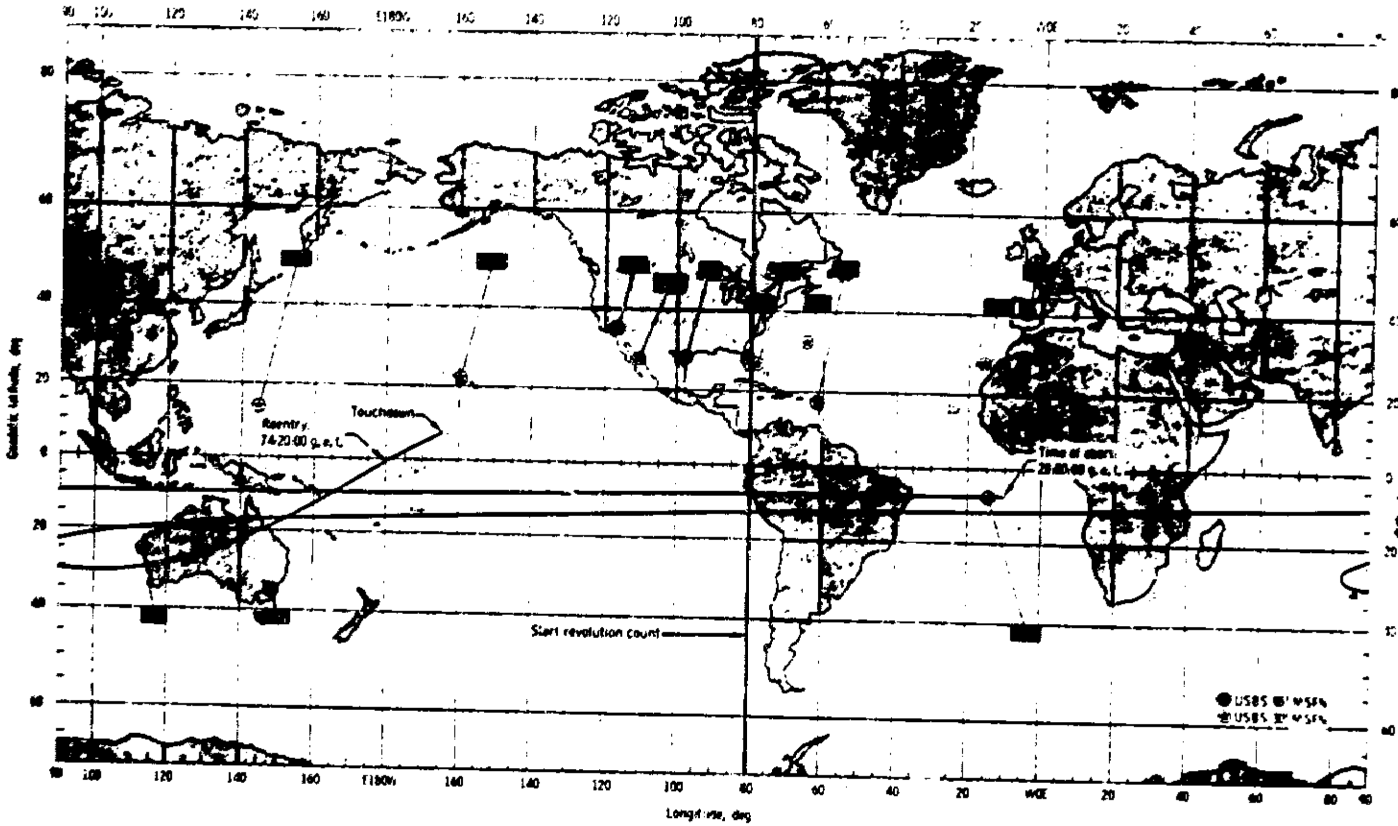
(e) 10L.

Figure 7-36. - Concluded.



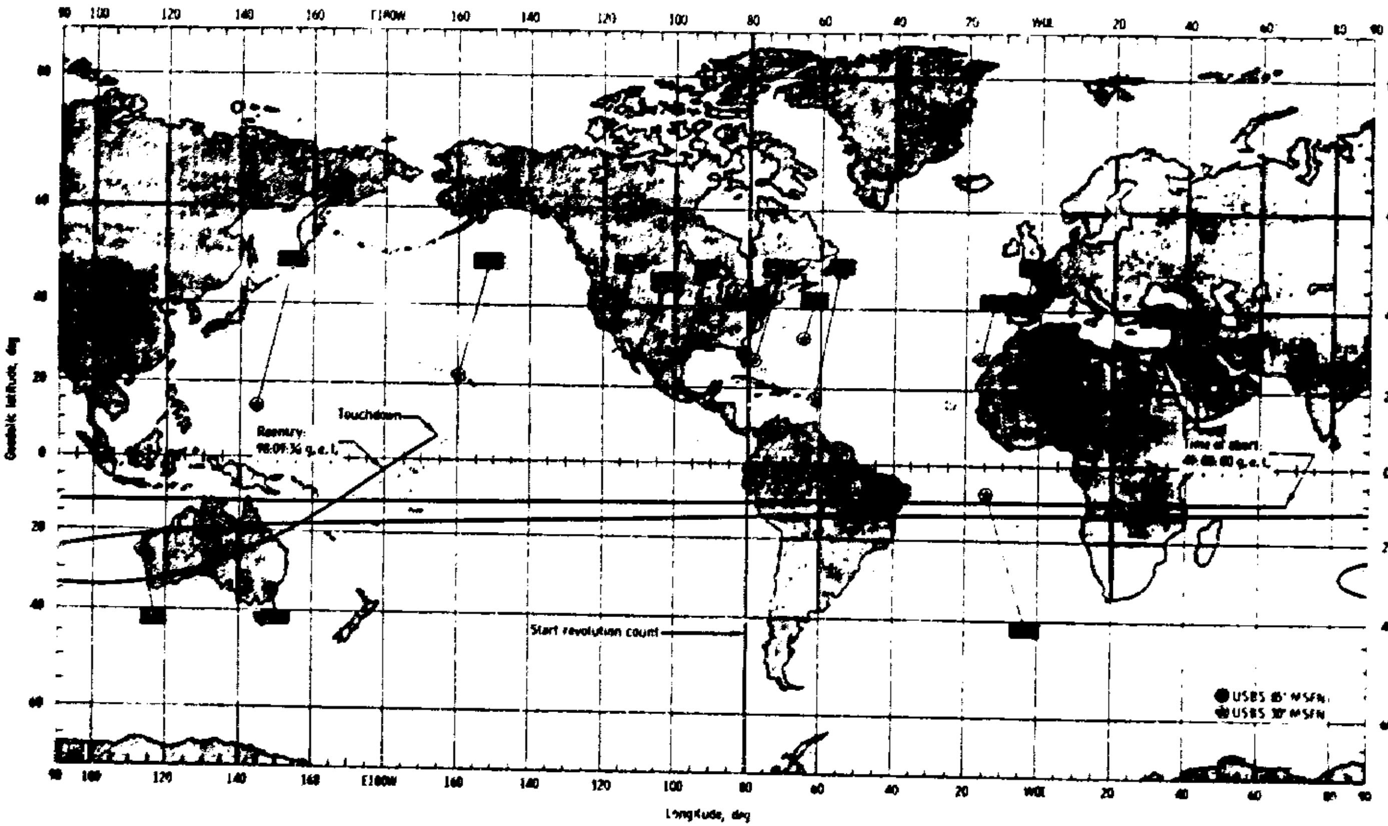
(a) 90 minute abort (04:26:00 g.e.t.)

Figure 7-37. - Postabort groundtracks for various abort times during TLC.



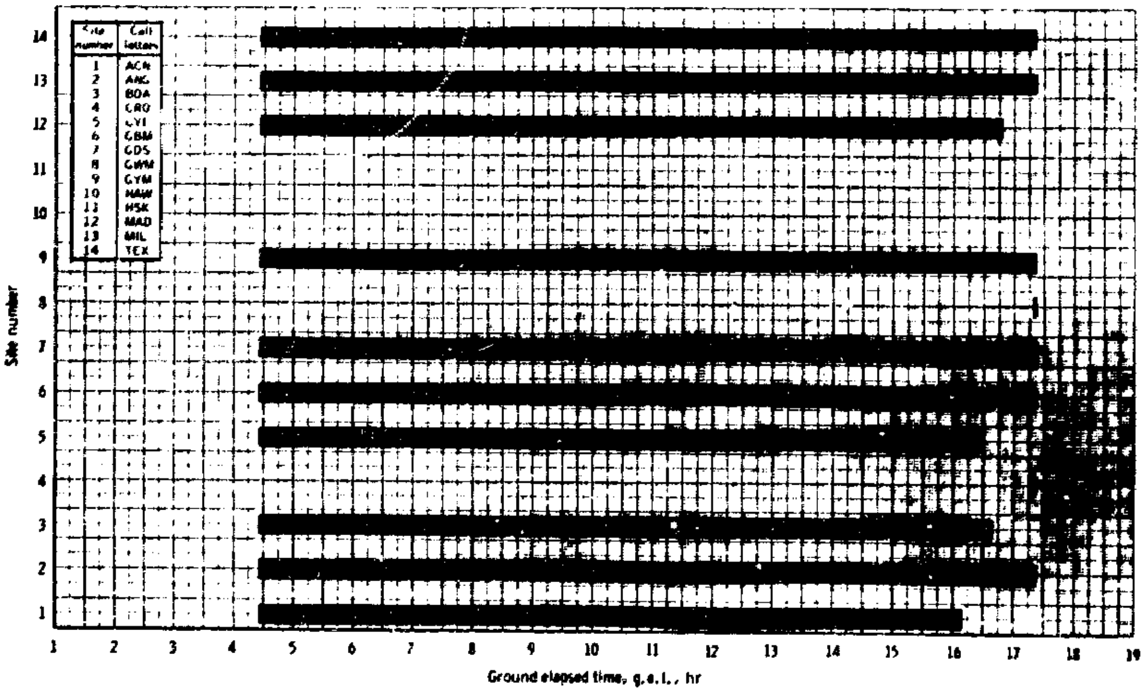
(b) 28 hour abort.

Figure 7-37. - Continued.



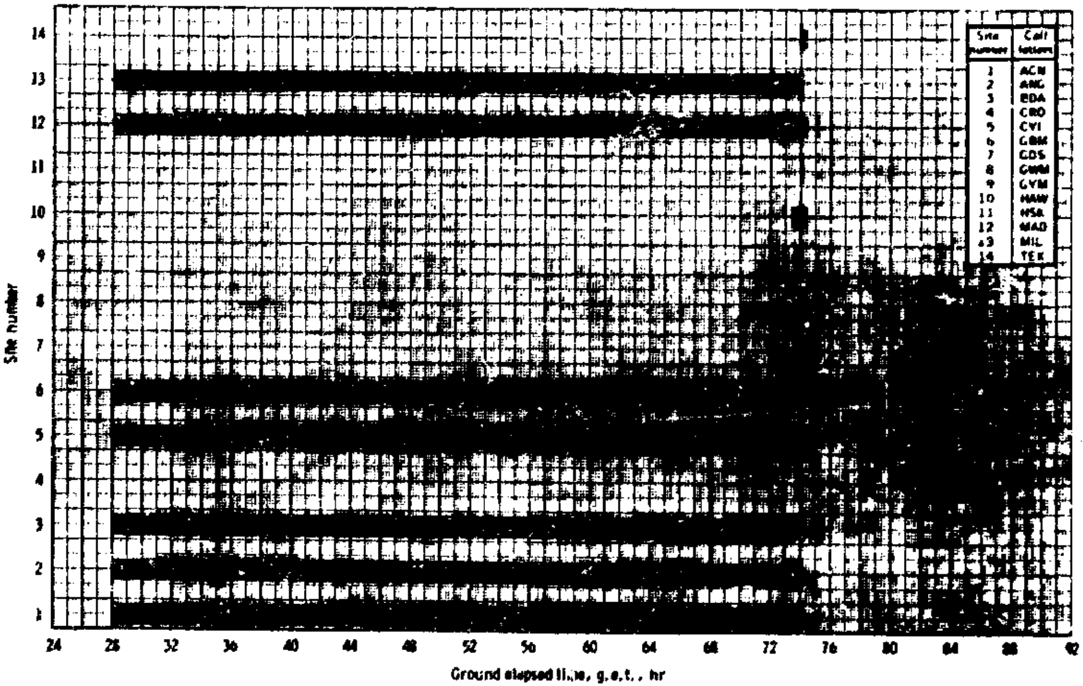
(c) 47 hour abort.

Figure 7-37. - Concluded.



(a) 90 minute abort.

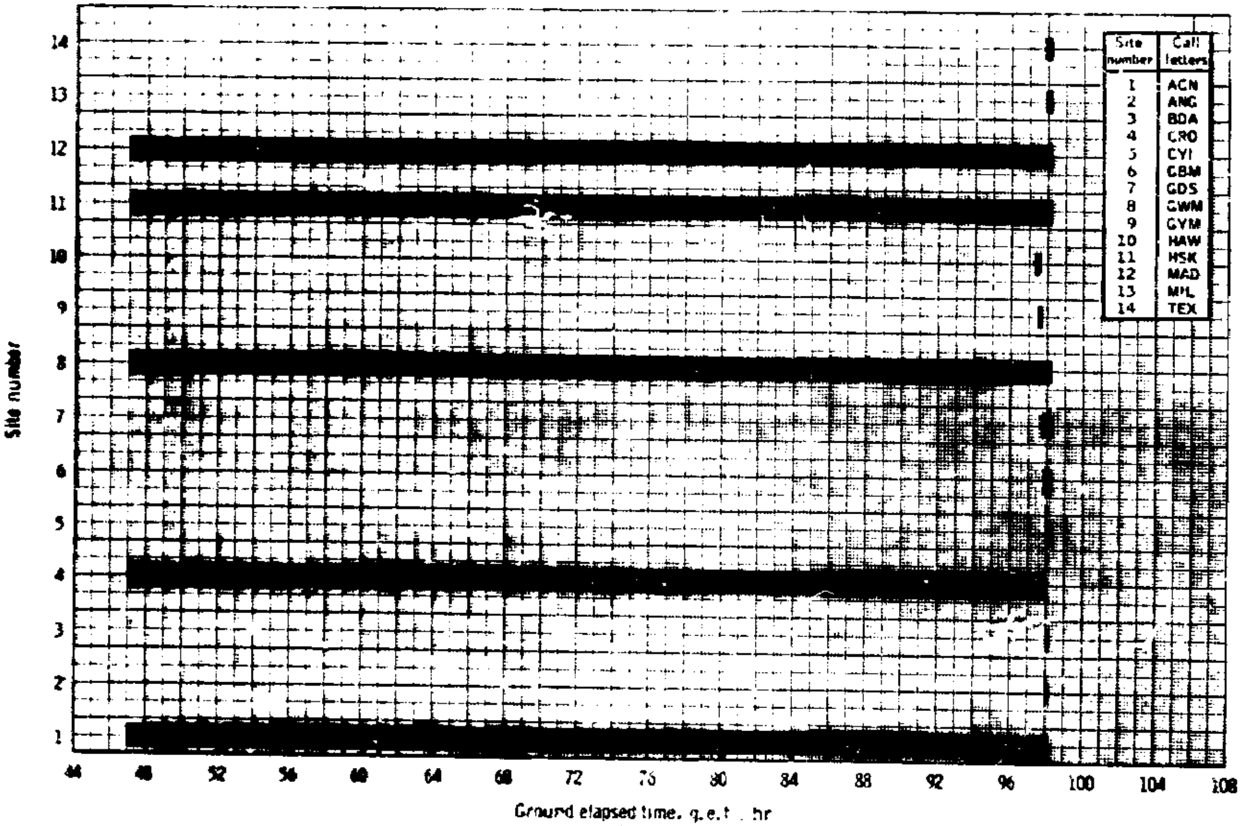
Figure 7-36. - Postabort radar tracking for 5° elevation.



27 hour 30 minute abort.

th[illegible]-hour abort.

Figure 7-36. - Continued.



48 HOUR 30 MINUTE ABORT,
(c) ~~47~~ hour abort.

Figure 7-38. - Concluded.

LUNAR ORBIT INSERTION
AND LUNAR ORBIT PHASE

8.0 LUNAR ORBIT INSERTION AND LUNAR ORBIT PHASE

8.1 Lunar Orbit Insertion Monitoring

Since LOI always occurs behind the moon, the crew must be able to evaluate the progress of the maneuver without ground support. Although there are two LOI burns required to produce the desired 60-n. mi. altitude circular orbit, the monitoring requirements are primarily for the first burn (LOI), because the second burn lasts only about 10 seconds. (Figure 7-3 depicted generally the recommended crew monitoring technique.)

Whereas crew safety is always the primary objective in defining monitoring procedures, an important second objective is assurance that adequate abort capability is provided and is compatible with possible results of the monitoring procedures. This second objective was accomplished for LOI by defining sound procedures for the two types of problems possible during LOI; that is, those perturbing the trajectory (type 1) primarily guidance and control problems, and spacecraft propulsion (type 2) or other system problems which do not affect the trajectory. It was recommended in reference 25 that problems of type 1 be handled by having the crew take manual control of the PGNCS-controlled maneuver and complete the LOI at the original ignition attitude. One of the most dangerous type 1 possibilities could occur if the spacecraft IMU drifts during LOI. For a small drift, the crew cannot detect its presence until an attitude deviation builds up and appears on the secondary inertial attitude reference. Since the drift could have occurred in the secondary reference as well as the IMU, the crew would have been unable to distinguish the erroneous system until it was discovered that the SCS attitude error needles (a third inertial reference) provide a tie-breaking capability. This would then enable a manual takeover and burn completion into lunar parking orbit. Since uncorrected IMU drifts in pitch can produce impacting trajectories, rules were then developed to define attitude limits for which a takeover should be initiated.

These rules and limits require a manual takeover with the SCS at 15° attitude deviation between ignition and 100 seconds and 10° attitude deviation after 100 seconds. In general, the 15° is for possible start transients, and the 10° is to prevent an undesirable pericynthion. Actually these numbers have more significance for transearth injection but are used for LOI as well as for simplicity. The effects on pericynthion of platform misalignments and constant drifts through LOI are plotted in figure 8-1. Effects of the takeover rules and limits are shown in figure 8-2. As pointed out above, a third inertial reference is required during LOI to insure that the IMU does not cause an impacting trajectory. Although there are three inertial reference systems in the spacecraft that could be used for LOI, an external reference such as the lunar horizon or stars may provide an additional reference.

As in TLI, the LOI rate limit is 10 deg/sec and results in a crew takeover and manual completion of LOI at ignition attitude.

Type 2 problems may dictate the necessity of an immediate abort maneuver which takes place 15 minutes after the crew shuts down a nominal trajectory. Problems of this type are primarily due to SPS problems and include loss of pressure or temperature increases, which generally means that the SPS engine could have a limited burn time constraint or maneuver capability. More specifically, the temperature problem is a result of a hot spot on the engine nozzle which could produce a hole and then an explosion. Increasing temperature is displayed to the crew by a flange temperature light in the spacecraft. Serious SPS pressure problems are

1. Sustained pressure decay in either fuel or oxidizer tank.

2. Thrust chamber pressure goes below 70 psi.

3. A delta pressure of greater than 20 psi between fuel and oxidizer tanks.

Although built-in redundancy may require two failures before these problems are time-critical, the desire to get the large (approximately 3000 fps) abort maneuver completed as soon as possible to insure lunar sphere escape is the major justification for the 15-minute abort mode.

Inadvertent shutdowns will be handled by ground control. Backup of the PGNCS LOI cutoff is performed by the crew primarily on a 6-second time bias to the nominal burn time. In summary, guidance and control problems during LOI result in crew takeover and burn completion to near nominal LOI end conditions from which an abort could be initiated, and SPS problems result in early LOI shutdown and abort.

8.2 Aborts During LOI and Lunar Orbit

8.2.1 Introduction.- The LOI burn transfer the spacecraft from a free-return circumlunar trajectory to the lunar parking orbit. The transfer consists of two SPS burns of approximately 246 and 10 seconds, respectively. Following the first burn (LOI 1) the spacecraft coasts in a 60- by 170-n. mi. altitude lunar orbit for two revolutions. The second LOI burn (LOI 2) is initiated at the third pericynthion to achieve the 60- by 60-n. mi. altitude lunar parking orbit.

Premature termination of the LOI maneuver places the vehicle in a nonnominal lunar orbit from which either an alternate mission or abort situation may result. An early shutdown of the SPS engine may occur as a result of two situations:

1. An early PGNCS shutdown.

2. Manual shutdown by the crew.

Manual shutdown should occur only in the event critical SPS systems problems which would severely restrict the future performance of the engine are encountered. The SPS systems malfunction limits (pressure and temperature) for a manual shutdown will require an abort maneuver which is executed as soon as possible. These limits will be specified in the Apollo 8 mission rules. By definition, therefore, manual shutdown of the SPS engine normally should not occur unless one of two situations exist:

1. Failure of the SPS engine is imminent.

2. Engine performance has been degraded and an absolute minimum of SPS operation is required.

For all other failure situations in which the option of continuing the burn is present, LOI burn completion has been shown to be desirable from an abort operations standpoint (ref. 26).

In the following sections, the primary differences in the abort procedures for manual and automatic cutoffs are discussed. General parametric data of abort ΔV and total flight times are included to illustrate the possible tradeoffs that can be made in the final selection of the abort solution. Finally, crew charts that are required for onboard return-to-earth targeting are included.

8.2.2 Characteristics of lunar trajectories resulting from premature LOI shutdown.- The lunar orbits which result from premature LOI shutdown can generally be classified in three distinct categories:

1. Class I - Result from shutdowns during the first 90 seconds of the LOI burn. These trajectories are hyperbolic with respect to the moon and will escape the moon's sphere of influence.

2. Class II - Result from shutdowns 90 to 120 seconds into the LOI burn. Trajectories of this type are very unstable and are greatly perturbed by the earth's attraction. The earlier shutdowns result in extremely long orbital periods. Later shutdowns have orbital periods as low as approximately 24 hours but impact the lunar surface prior to pericynthion.

3. Class III - Result from shutdowns 120 seconds to nominal LOI 1 shutdown (approximately 246 seconds). These are stable lunar ellipses with nonimpacting pericynthions.

Figure 8-3 shows the conic parameters at LOI cutoff as a function of SPS burn time during the LOI burn. Shutdowns during the latter half of the LOI burn result in orbits from which either aborts or alternate missions might occur. Such an alternate mission is basically nothing more than an off-nominal LOI 2 burn and the total ΔV of LOI 1 and LOI 2 would be very near that of the normal LOI technique. On the other hand, unless a corrective maneuver is made to reduce the orbital period and provide a clear pericynthion, shutdowns prior to 120 seconds necessitate an abort.

8.2.3 Abort modes.- Lunar phase abort maneuvers for the Apollo 8 mission are of two basic types.

1. Mode I - A one-impulse maneuver which returns the spacecraft directly to earth. The abort burn is initiated as soon as possible after LOI shutdown to reduce the necessary ΔV. The range of LOI shutdown times that the mode I abort is available is a function of the abort ΔV available and the delay time to abort initiation.

2. Mode III - A one-impulse maneuver which occurs near pericynthion following one or more revolutions in lunar orbit. The actual time of abort initiation is a function of the desired transearth time and the preabort period. Mode III aborts are available after 120 seconds into the LOI burn where free pericynthions exist.

Figure 8-4 shows the abort mode overlap that exists for the Apollo 8 mission. For a substantial range of LOI shutdowns, both a mode I and mode III abort are possible due to the magnitude of the SPS ΔV that remains following premature LOI shutdown (fig. 8-5). It should be noted, however, that a return-to-earth capability exists with the SM RCS for only the first 15 seconds of the LOI burn. For shutdowns past this point in the LOI burn, the abort ΔV would require use of the SPS engine.

8.2.4 Abort ground rules.- The abort ground rules for LOI aborts are as follows:

1. If a guidance cutoff occurs prematurely and a non-impacting pericynthion has not been achieved (LOI burn time < 120 seconds), a mode I abort will be initiated as soon as possible using an RTCC solution.

2. If a guidance cutoff occurs prematurely and a stable lunar orbit exists, either an alternate mission or abort may result. If communications are available and an abort decision is made, an RTCC targeted mode III abort will be initiated.

3. If a guidance cutoff occurs and communications are not available, the following backup abort technique will be followed:

a. LOI burns 0 to 80 seconds - The CSM will coast to the MSI where the CMC P-37 can be used for return-to-earth targeting. The return-to-earth solution is determined, and an MCC is applies using the SPS. (The largest ΔV which would result is 3000 fps for shutdowns at 80 seconds.)

b. LOI burns 80 to 120 seconds - The crew will initiate a mode I abort maneuver at 5 hours past LOI shutdown using a crew chart.

c. LOI burn 120 seconds to the end of LOI 1 - A mode III abort will be initiated using crew charts.

4. If a manual SPS shutdown is required due to engine pressure or temperature problems, the following criteria could be used to determine the abort mode:(although the crew has the option of using the mode I 15 minutes crew chart for manual shutdowns at any point in the LOI burn:

a. LOI burns 0 to 120 seconds - A mode I abort maneuver should be initiated at 15 minutes using a crew chart.

b. LOI burns 120 seconds to end LOI 1 - A 15-minute mode I abort maneuver should be initiated for time critical SPS engine problems. However, for minimum ΔV SPS problems, a mode III RTCC abort solution will be used.

c. If the 15-minute abort were not possible and subsequent communications failures occur, the backup abort technique in ground rule 3 should be used.

8.2.5 Parametric abort data as a function of LOI shutdown.- This section includes a description of the abort ΔV requirements for the RTCC generated abort solutions. The crew charts are contained in section 8.2.7.

Figure 8-6(a) shows the minimum mode I abort ΔV required as a function of LOI shutdown time. It is evident that the ΔV initially increases very rapidly as the delay time from LOI shutdown to abort is increased. However, due to the magnitude of the SPS ΔV available (as indicated on the figure), the 15-minute solution exists for the entire LOI 1 burn. Figure 8-6(b) indicates the total time from LOI shutdown to earth landing (TFT) for the abort maneuvers of the previous figure. Of primary interest is the fact that the later the mode I abort is delayed, the greater will be the TFT.

In a normal abort situation, however, a return to a planned recovery area would be preferred. Figures 8-7(a), (b), and (c) show the abort ΔV for mode I returns to the MPL as a function of LOI shutdown time.

Figures 8-7(a), (b), and (c) show returns with TFT values of 53 hours 77 hours, and 101 hours, respectively. At this point a major difference between unspecified area returns and planned landing area returns should be indicated. For a particular LOI shutdown time and a given TFT to the desired landing area, the ΔV requirements do not necessarily increase with initial delay time to abort. For early shutdowns this becomes evident (fig. 8-7).

Mode III abort solutions require much less ΔV than mode I aborts at a particular LOI shutdown. Figure 8-8(a) presents the abort requirements for mode III returns to the MPL. Comparison of each constant TFT solution for the mode III aborts with the mode I solutions of figure 8-7 shows the decrease in abort ΔV that can be achieved by coasting one revolution prior to abort. The minimum ΔV for unspecified area mode III returns is also shown on figure 8-8(a) and the corresponding TFT is indicated on figure 8-8(b).

8.2.6 Abort analysis of specific LOI shutdowns.- Aborts for LOI shutdowns may be described as follows:

1. LOI shutdown at 60 seconds (class I preabort trajectory) - Figure 8-9 presents the abort ΔV and TFT for mode I aborts following a premature LOI shutdown. In order to show the relative requirements for returns to a variety of landing areas, returns to the MPL, AOL, EPL, WPL, and IOL are included. As indicated in the previous discussion, a considerable tradeoff of abort ΔV and TFT can be made by varying the time of ignition when returns to contingency landing areas are desired. However, the minimum ΔV for unspecified area earth return still has the familiar characteristic of increasing with initial delay time, as shown on figures 8-9(a) through (e). The TFT corresponding to these FCUA returns is shown in figure 8-9(f).

2. LOI shutdown at 120 seconds (class III preabort trajectory) - Figure 8-10(a) shows the abort mode I ΔV required for returns to the MPL as a function of initial delay time. Except for the considerable increase in abort ΔV over the 60-second LOI shutdown, the two sets of curves are similar and the same discussion is applicable here. The mode I FCUA TFT appears in figure 8-10(b).

The trajectory in this case is the first of the class III trajectories and permits the use of the more desirable mode III abort. Figure 8-11(a) shows the abort ΔV for the mode III abort. Both types of returns, MPL and FCUA, exhibit a substantial decrease in abort ΔV compared to the mode I solutions of figure 8-10(a). The 53-hour TFT return is no longer available due to the 17-hour period of the preabort ellipse. After one revolution the entry velocity of 36 333 fps would be exceeded if an attempt at a 53-hour TFT was made. The FCUA TFT is shown on figure 8-11(b) for various delay times from LOI shutdown.

3. Nominal end LOI 1 shutdown (60- by 170-n. mi. altitude lunar orbit) - The abort ΔV requirements for a mode III abort to the MPL are included as figure 8-12(a). The FCUA returns are presented in the same figure and the corresponding FCUA TFT are on figure 8-12(b). A characteristic of mode III aborts is evident from figure 8-12(a). Specifically, when several constant TFT solutions are available, the longest TFT abort solution would be initiated first. All LOI mode III aborts exhibit this same characteristic.

4. Nominal end LOI 2 shutdown (aborts from the nominal 60- by 60-n. mi. altitude lunar orbit) - This discussion is included with the premature LOI shutdown description for continuity. However, it should be noted that aborts out of the nominal 60- by 60-n. mi. altitude lunar orbit are identical to the normal TEI burn. For completeness data is shown for returns to the MPL, AOL, EPL, WPL, and IOL recovery areas [fig. 8-13(a) through (e)]. The FCUA TFT is presented in figure 8-13(f).

8.2.7 LOI crew charts.- The crew charts mentioned in section 8.2.1 can be briefly summarized as follows:

1. Mode I 15-minute crew chart - This crew chart is used in the event a manual LOI shutdown occurs and an immediate abort maneuver is required. Following LOI shutdown, the crew maneuvers the CSM to the correct inertial thrust attitude based on a set of gimbal angles relative to the pre-LOI IMU orientation. The abort maneuver is initiated 15 minutes following SPS shutdown. The abort ΔV magnitude is determined from a crew chart.

2. Mode I 5-hour crew chart - This crew chart is used in a manner identical to the mode I 15-minute chart. The main difference, however, is that the mode I 5-hour chart is only used as a backup to the RTCC computed solutions in the event communications failures occur. Only one curve is required, abort ΔV as a function of LOI burn ΔV magnitude.

3. Mode III crew chart - This data is used as a backup to RTCC calculations and consists of two charts. The first chart presents abort ΔV as a function of LOI ΔV magnitude. The second chart is used to determine the time of ignition.

Figure 8-14(a) is a condensation of the abort ΔV required charts and includes data for mode I 15-minute, mode I 5-hour, and mode III crew charts. Figure 8-14(b) presents the mode III time of abort. Both curves are based on the ΔV magnitude of the LOI burn read from the DSKY at shutdown with LOI burn time as a backup.

8.2.8 Crew chart midcourse requirements.- Before discussing the midcourse requirements of the LOI crew charts, an important comment should be made. The basic reason for using onboard crew charts for abort maneuvers inside the MSI is that no onboard computer program is available to perform this task. The onboard return-to-earth program (CMC P-37) can calculate aborts or MCC's only if the CSM is outside the MSI at time of ignition.

Normally, the return-to-earth targeting will be done using RTCC solutions transmitted from the ground following the abort decision. If a premature LOI shutdown occurs the previously transmitted RTCC abort solutions (block data, section 8.2.9) are not applicable since nonnominal orbits result from the early burn termination. Therefore, the ground will transmit an abort solution calculated in the RTCC. However, if communications are lost or if the spacecraft is in a position where it could not receive the solution (behind the moon in the case of the mode I 15-minute abort), onboard data is required. The basic function of the crew charts, therefore, is to provide an abort solution that will result in CSM exit of the MSI and have MCC requirements with the ΔV remaining.

The crew charts are used for all launch azimuths and opportunities and the MCC ΔV varies accordingly. It appears likely that the MCC ΔV will require use of the SPS engine. An attempt will be made to update the mode I 15-minute chart during the final hours prior to LOI if significant trajectory deviations occur. For all charts, the gimbal angles will be recomputed based on the actual REFSMMAT used for LOI, and transmitted with the pre-LOI block data.

Figures 8-15(a) through (d) show the expected MCC ΔV at the MSI for various execution errors. Based on this data and the assumption of a midcourse ΔV from the RCS of 100 fps, it can be seen that the following execution errors[a] can be tolerated within RCS midcourse capability:

pitch error = ±1.5 deg

yaw error = ± 6.0 deg

ΔV error = ±50 fps

t_{ig} error = ±15 sec

For larger execution errors an SPS midcourse would be required.

---

[a]These errors are for shutdowns at the end of LOI 1 burn where the MCC ΔV requirements are the largest. All earlier shutdowns have much smaller MCC ΔV values

That is, a subsequent engine failure would be catastrophic with no possibility of aborting.

An important fact that should also be considered for the 15-minute abort is that a communications failure has not necessarily occurred. Contrary to the normal use of onboard charts, this abort mode was based only on SPS engine problems. Therefore, an MCC could be performed soon after the CSM appears from behind the moon and a large reduction of midcourse ΔV could be achieved using an RTCC solution.

Figures 8-16(a) through (d) show midcourse requirements at the MSI for the mode III crew chart maneuver. The following errors[a] can be tolerated using the assumptions of the mode I discussion.

pitch error = ±2.0 deg

yaw error = ±2.0 deg

ΔV error = ±50 fps

t_{ig} error = 24 sec

The most obvious conclusion is that an SPS midcourse will very likely be required. This remains consistent with the abort ground rules in section 8.2.4, however; that is, for SPS engine problems that become evident during the LOI burn, a manual shutdown will occur and a 15-minute mode I abort will be initiated. The use of mode III crew charts, therefore, is generally restricted to problems with CSM systems other than the SPS engine along with a subsequent communications failure.

The sensitivities of the mode I 5-hour crew chart are not included in this discussion but it can be assumed that an SPS midcourse will also be required.

The midcourse calculations for the mode III crew chart aborts will be calculated using the onboard return-to-earth program CMC P-37. This program can only be used outside the MSI, however.

8.2.9 Block data solutions.- During the last hours of the translunar coast, abort solutions will be transmitted to the crew to provide onboard targeting capability inside the MSI. Specifically, these primary solutions are considered:

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[a]These errors are for shutdowns at the end of LOI 1 burn where the MCC ΔV requirements are the largest. All earlier shutdowns have much smaller MCC ΔV values.

1. 60-by-170 block data - Following the final MCC on the translunar coast, an abort solution will be transmitted to cover communications failures following the LOI 1 burn. This solution would return the CSM to the primary landing area.

2. 60-by-60 block data - During the 60- by 170 n. mi. altitude orbit coast, a previously-sent abort solution for the nominal lunar parking orbit (60- by 60-n. mi. altitude) will be updated to account for any dispersions in LOI 1. This solution is again updated once LOI 2 is completed. During each of the eight remaining lunar orbits, an abort solution to the primary landing area is transmitted.

3. 2-hour post-pericynthion block data - Prior to LOI an abort solution is transmitted to the crew for an abort initiated 2 hours past pericynthion on the nominal free-return trajectory. This solution would be used if time-critical CSM problems occur along with communications failures. This abort solution is targeted to the contingency landing area that permits the fastest earth return.

Table 8-I contains general data pertaining to these block data abort solutions.

[illegible] - BLOCK DATA FOR LUNAR PHASE ABORTS

[illegible]	Case	[illegible]			ΔV_T, fps	Δt_B, [illegible]	TAR, hr:min:sec	V_{EI}, fps	γ_{EI}, fps	ϕ_L, deg	λ_L, deg	External ΔV targets		
		[illegible], deg	[illegible], deg	[illegible], deg								ΔV_X, fps	ΔV_Y, fps	ΔV_Z, fps
[illegible]	1[a]	179	275	[illegible]	[illegible]	2:17.6	51:35:34.0	36 271.78	-6.30	7.03	195.03	1468.3	-131.2	-522.5
[illegible]	2[b]	[illegible]	[illegible]	354	[illegible]	2:57.1	51:35:52.0	36 269.34	-6.30	6.82	195.03	5694.9	-154.1	-2150.0
[illegible]	3[c]	[illegible]	7	[illegible]	[illegible]	[illegible]	[illegible]:24:18.0	36 186.50	[illegible]	0.95	195.00	1596.2	-10.8	146.5
[illegible]	4[d]	179	[illegible]	[illegible]	3756.2	3:41.6	51:15:23.0	36 299.47	-6.31	5.47	194.97	3734.3	-318.2	250.6
[illegible]	5[e]	[illegible]	20	1	[illegible]	3:00.9	71:44:12.8	36 101.97	-6.26	1.77	195.00	3002.3	-32.6	-0.7
[illegible]	6[f]	[illegible]	324	[illegible]	[illegible]	1:55.9	[illegible]	36 230.37	-6.44	4.24	195.03	1509.7	-156.8	-1784.6
[illegible]	7[g]	[illegible]	[illegible]	[illegible]	[illegible]	2:47.3	[illegible]:04:55.6	36 270.00	-6.30	-0.26	195.01	3059.0	-161.2	3.8

[a] [illegible] 2 hours [illegible] on free return trajectory.

[b] [illegible] at 60 seconds. [illegible] 2 hours past shutdown.

[c] [illegible] at 120 seconds. [illegible] after 1 revolution.

[d] [illegible] after 1 revolution in 60 × 170 [illegible]

[e] [illegible] after 1 revolution in 60 × 60 [illegible]

[f] [illegible] at 140 seconds. [illegible] 2 hours past shutdown.

[g] [illegible] at 60 seconds. [illegible] after 1 revolution.

[h] [illegible] = 180°, [illegible]

TABLE 8-II.- GIMBAL ANGLES FOR LOI CREW CHARTS AND ATTITUDE REFERENCE

Reference REFSMMAT

X	-.64877632	-.66111865	-.37684405
Y	.076384116	-.54928435	.83213711
Z	-.7571359	.51106595	.40686163

IMU Gimbal Angles

	IGA	MGA	OGA
Mode I 15 min	27.857	1.989	-177.868
Mode I 5 hr	7.389	-2.886	0.890
Mode III	67.918	2.416	-178.443

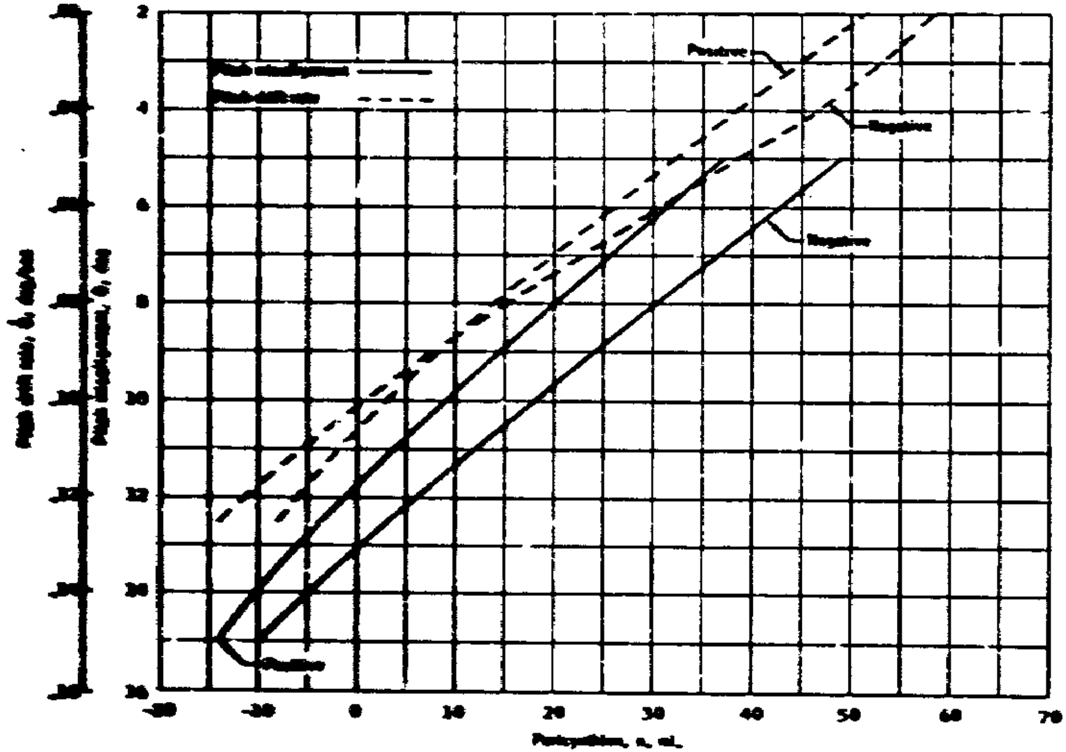


Figure 8-1. - Pericynthion altitude for simulated IMU pitch drifts and misalignments during LOI.

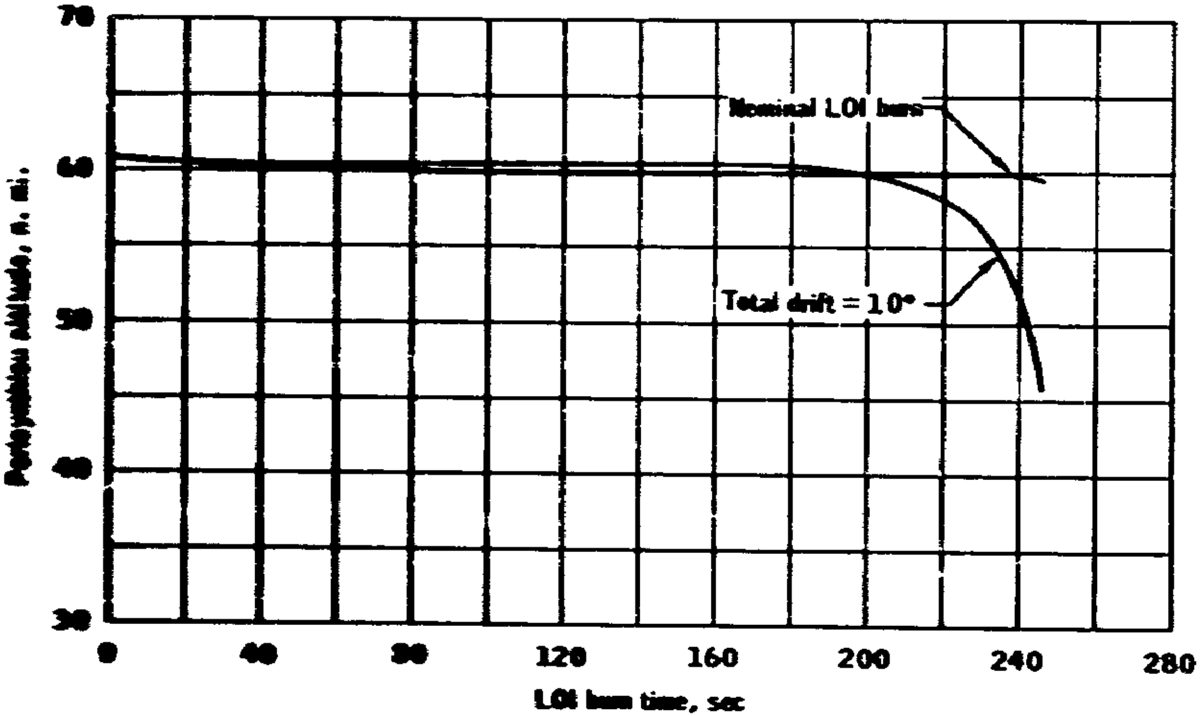


Figure 8-2.- Pericynthion altitude for a nominal and drifting LOI burn.

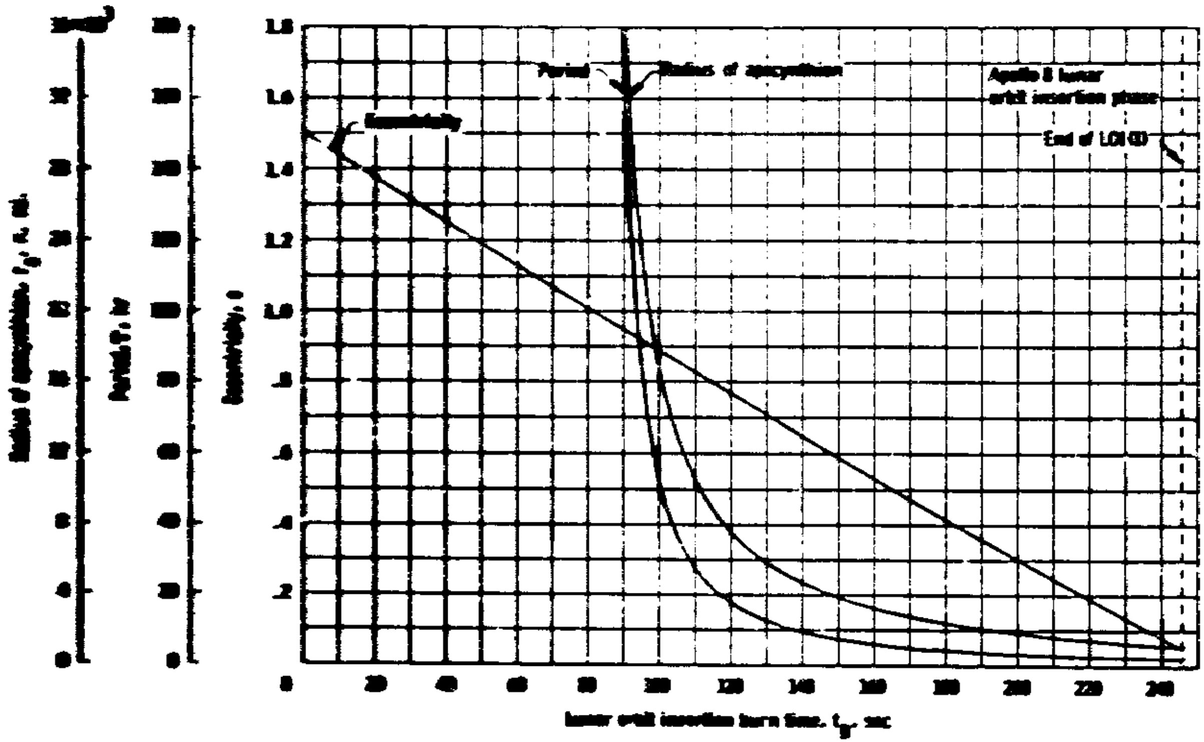


Figure 8-3. - Conic parameters as a function of SPS burn time during the LOI burn.

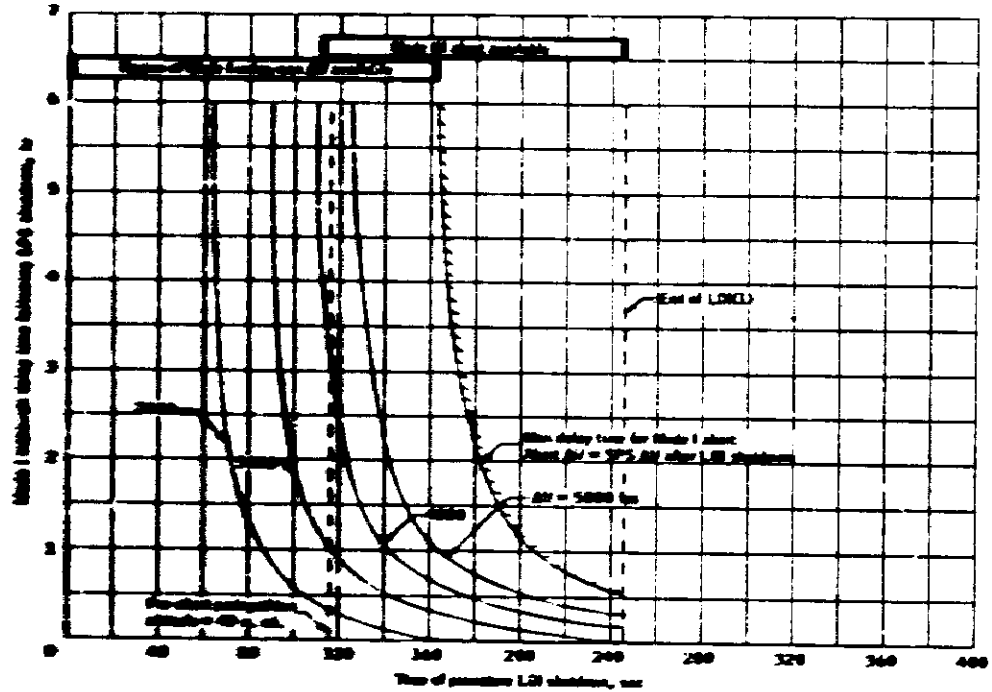


Figure 8-4.- Lunar orbit insertion abort mode overlap.

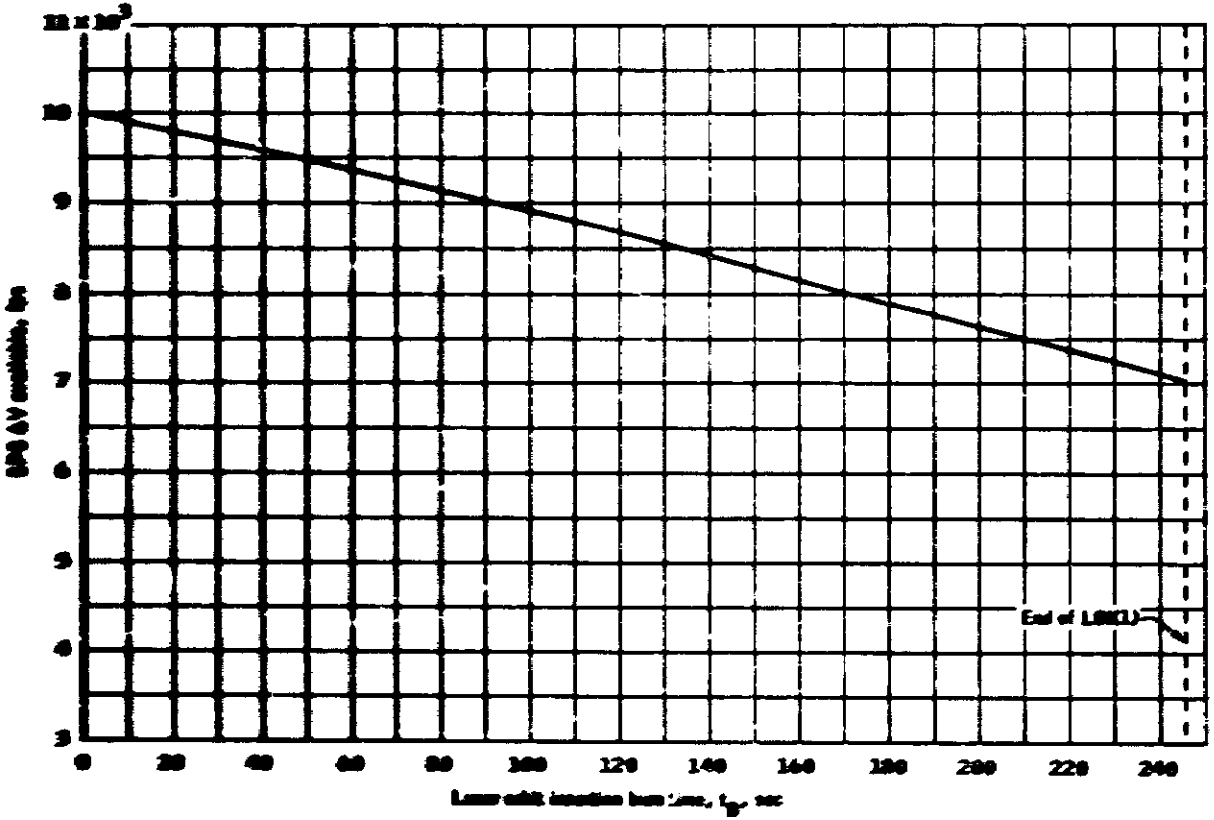
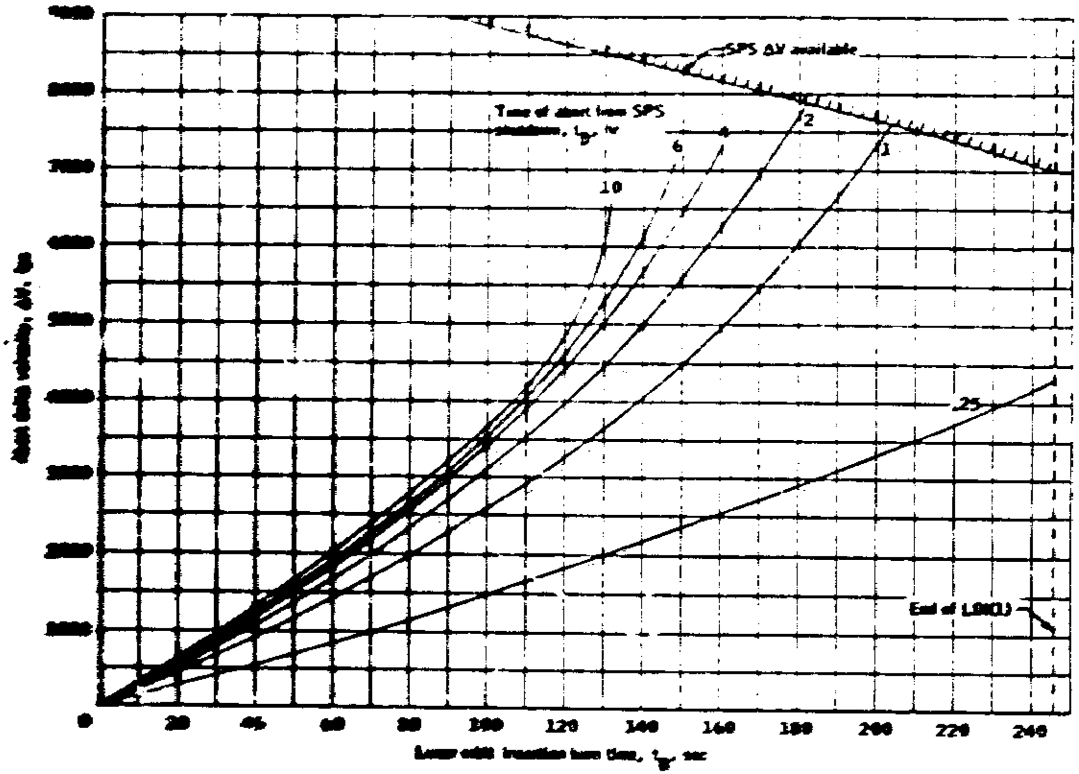
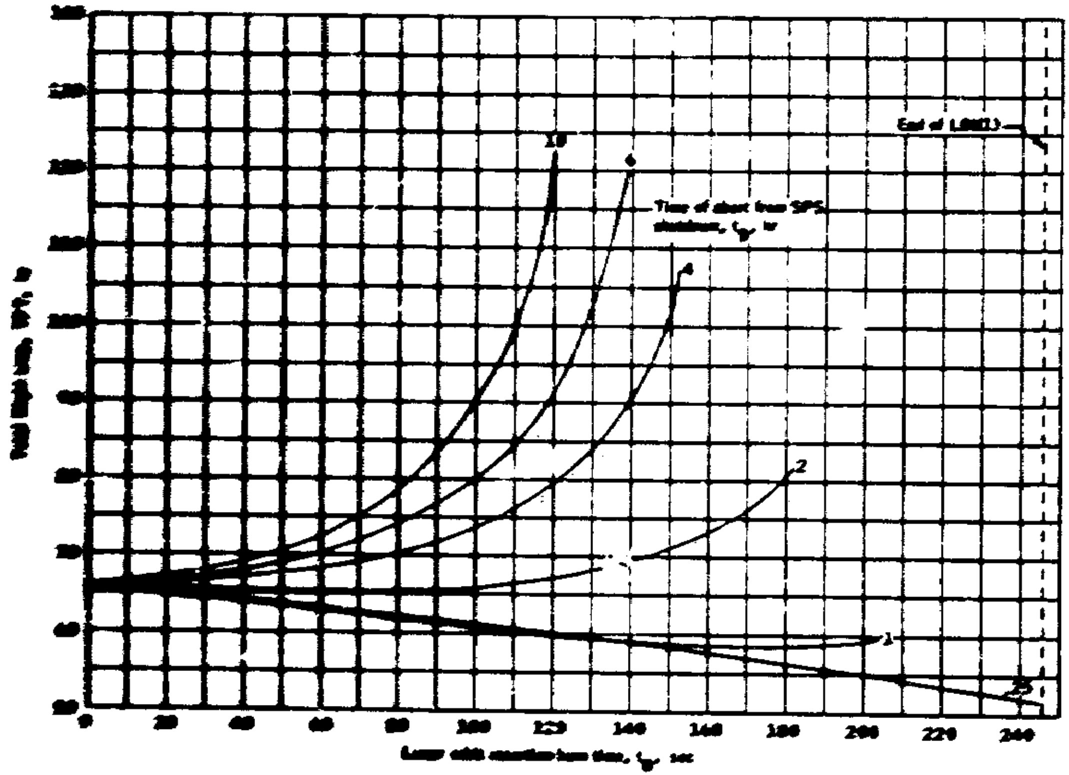


Figure 9-5.- SPS delta-velocity available following a premature SPS shutdown during the LOI burn.



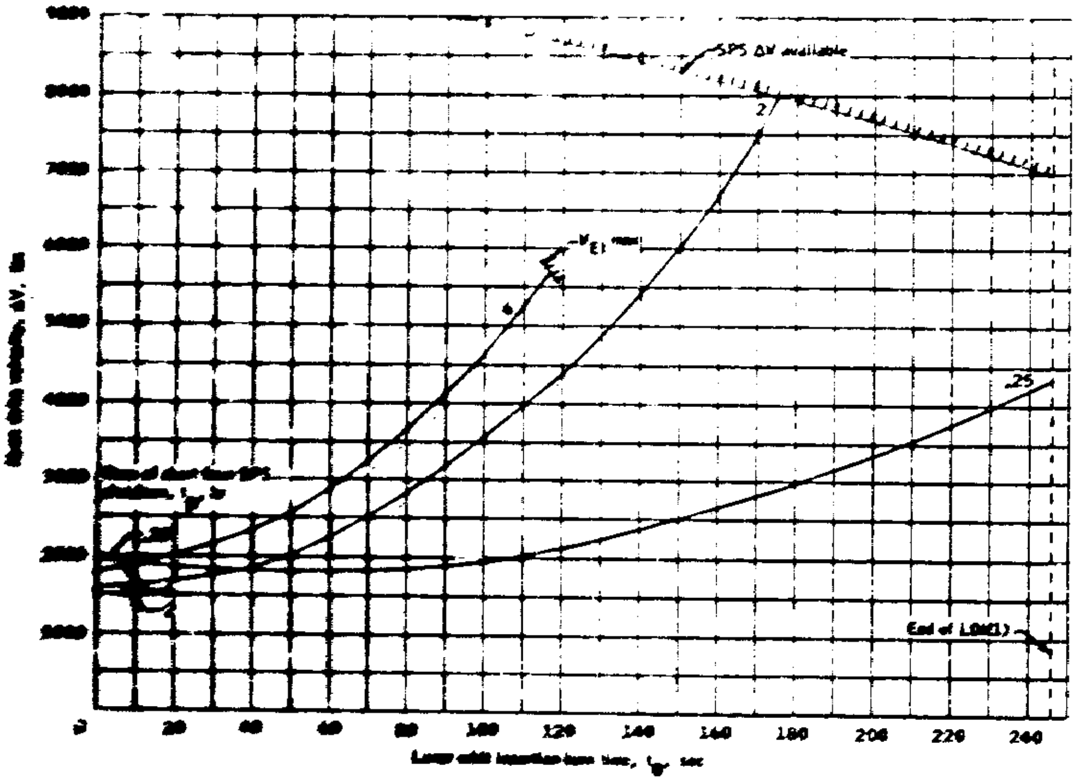
[illegible] as a function of LOI burn time.

[illegible] for various LOI burn times.



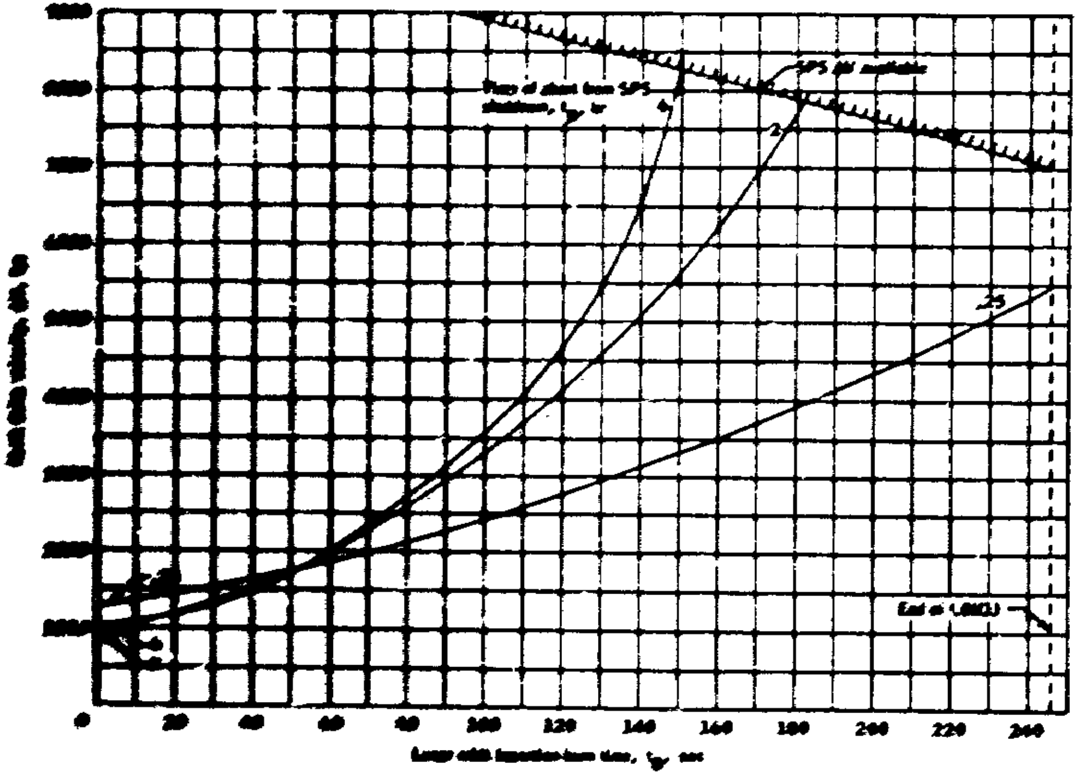
(b) Total flight time as a function of LOI burn time.

Figure A-6.- Concluded.



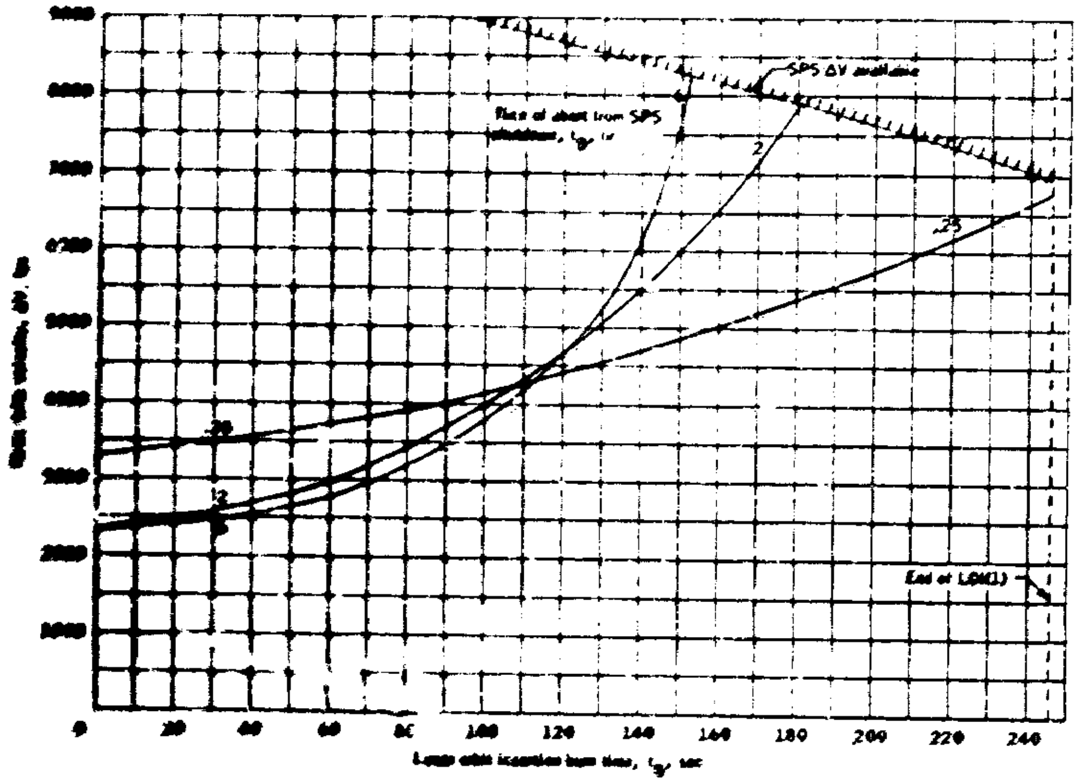
(a) [illegible] ΔV for [illegible] (TFT = 53 hours).

Figure [illegible].- [illegible] contingency landing area abort analysis for various LOI burn times.



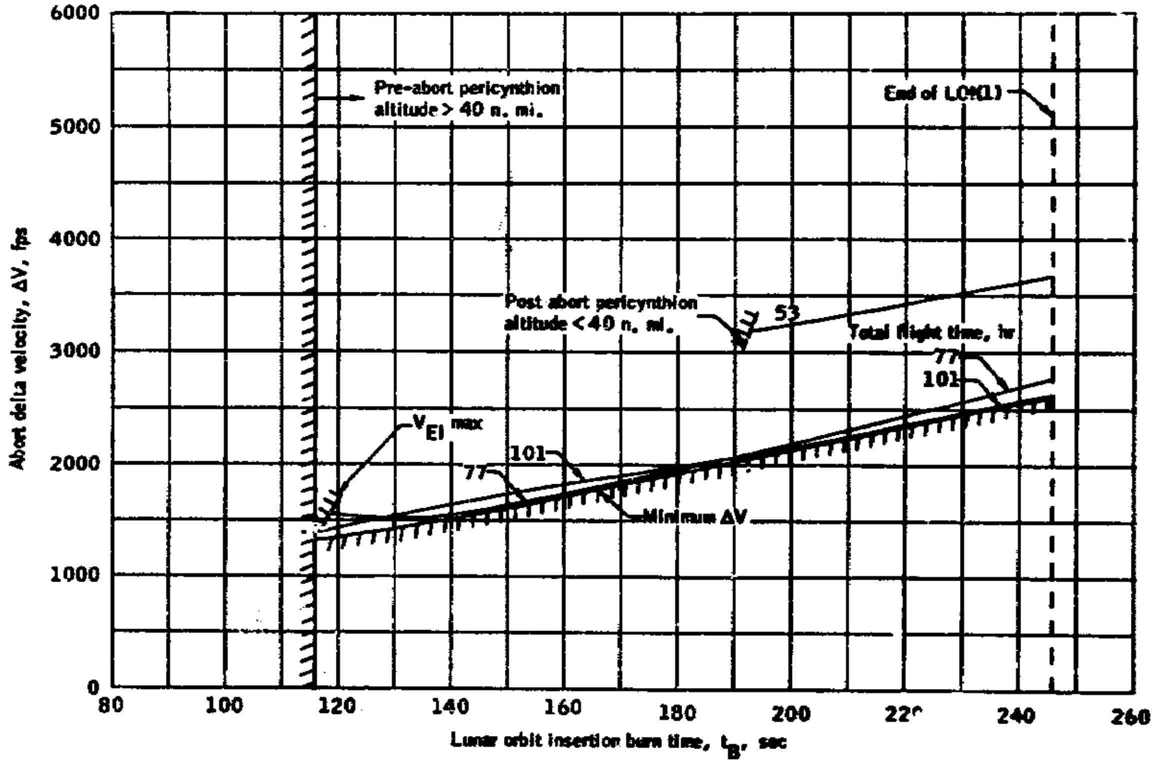
[illegible] (WFT = 77 hours).

Figure 8-7.- Continued.



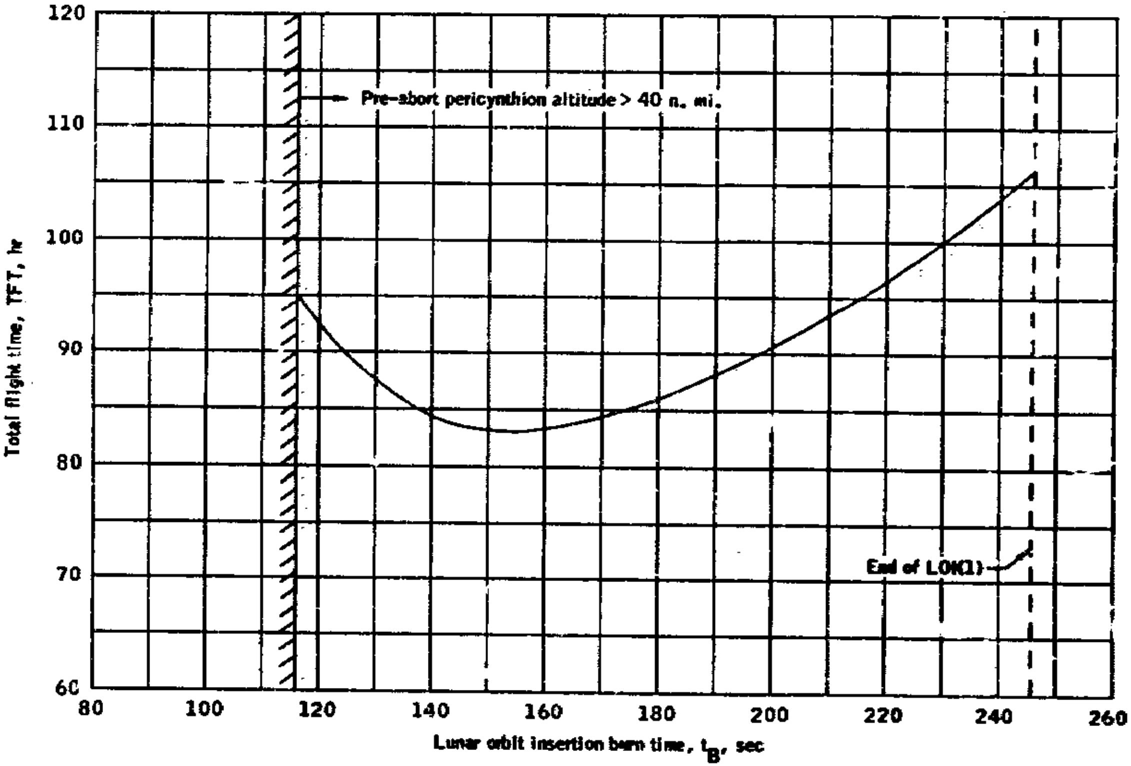
(d) Abort ΔV for MPL returns (TFT = 101 hours).

Figure 8-7.- Concluded.



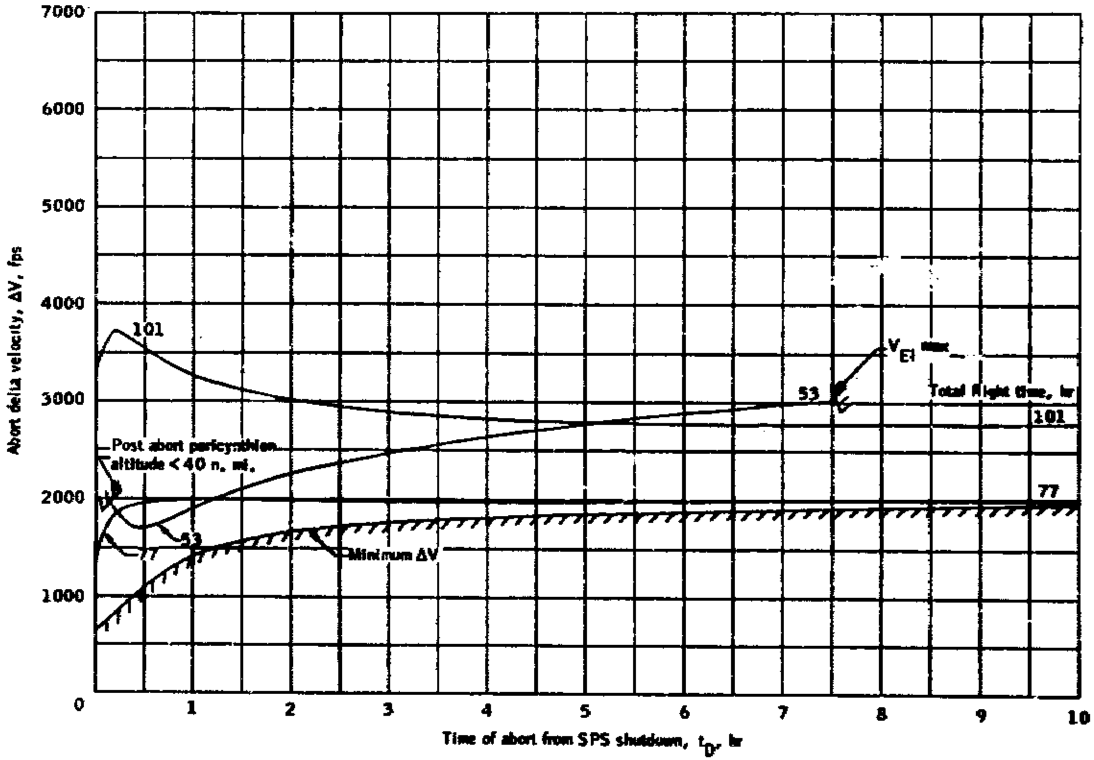
(a) Abort ΔV for MPL and fuel critical unspecified area returns.

Figure 8-8.- Mode III abort analysis for various LOI burn times.



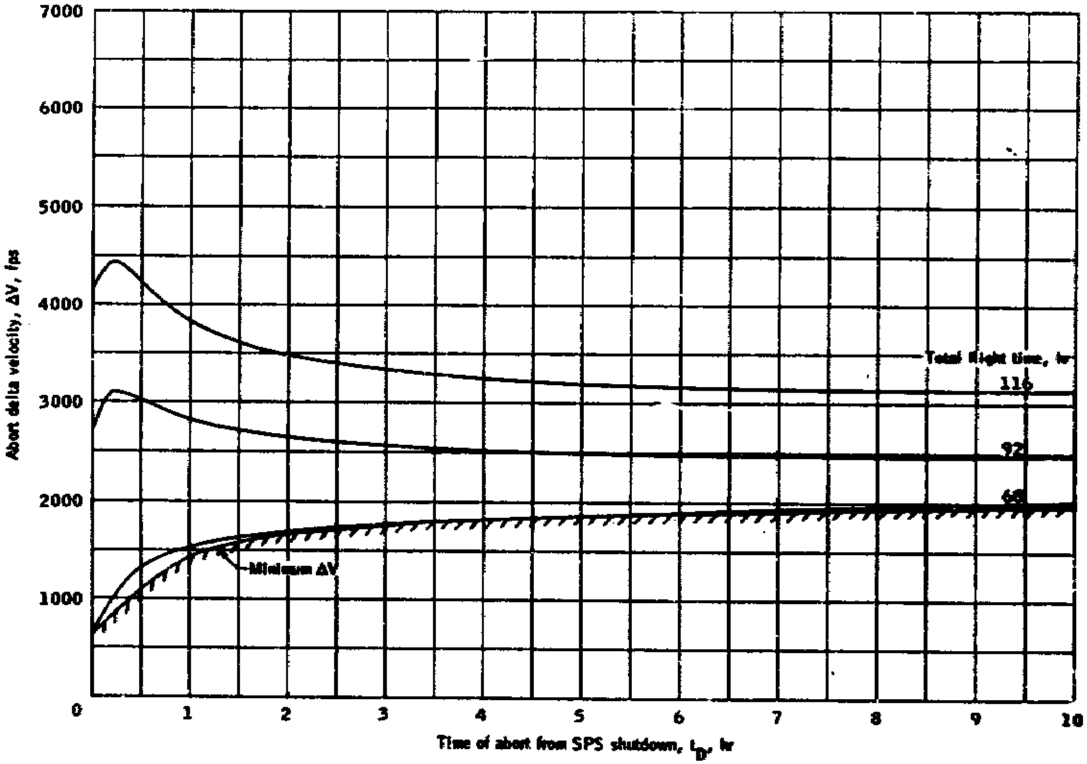
(b) Total flight time for fuel critical returns as a function of LOI burn time.

Figure 8-8.- Concluded.



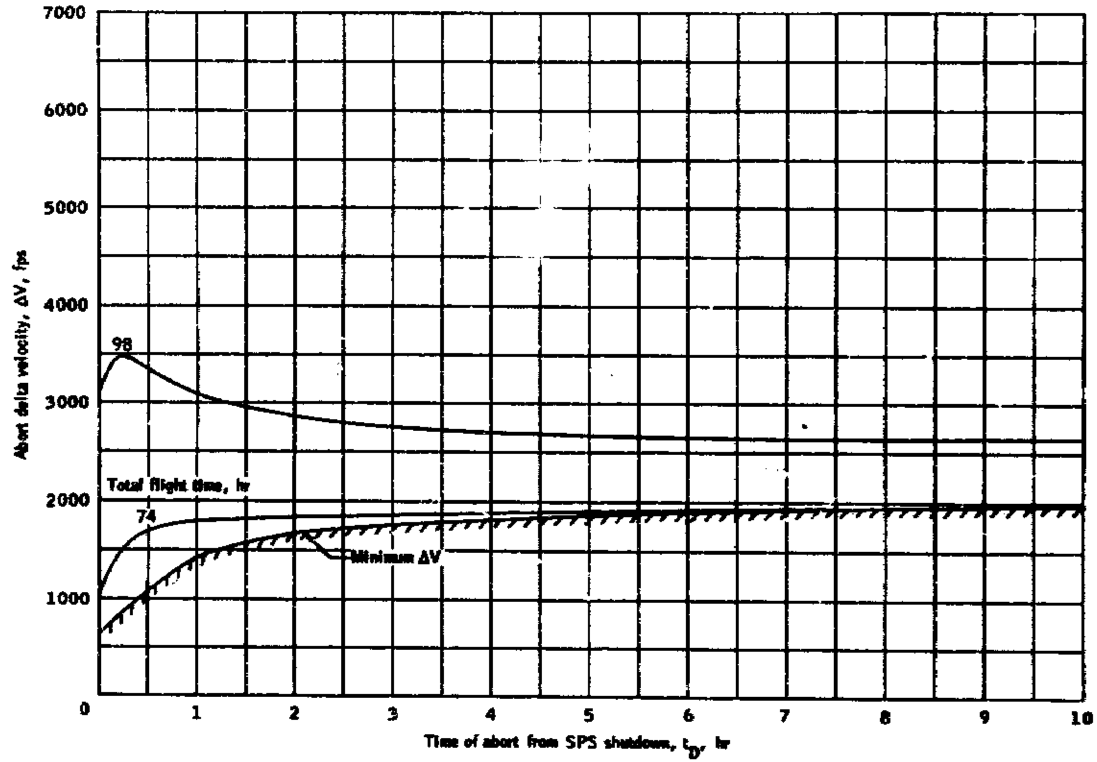
(a) Abort ΔV as a function of delay time from LOI shutdown (MPL and FCUA returns).

Figure 8-9.- Mode I abort analysis for LOI shutdown at 60 seconds.



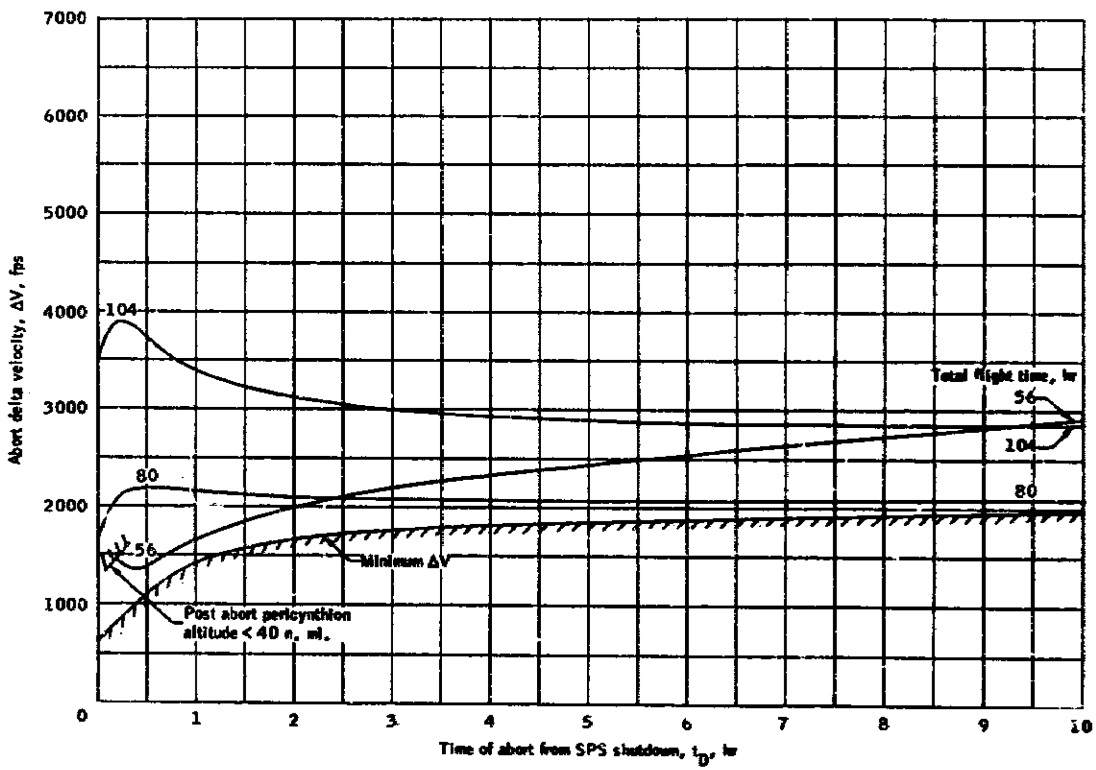
(b) Abort ΔV as a function of delay time from LOI shutdown (AOL).

Figure 8-9.- Continued.



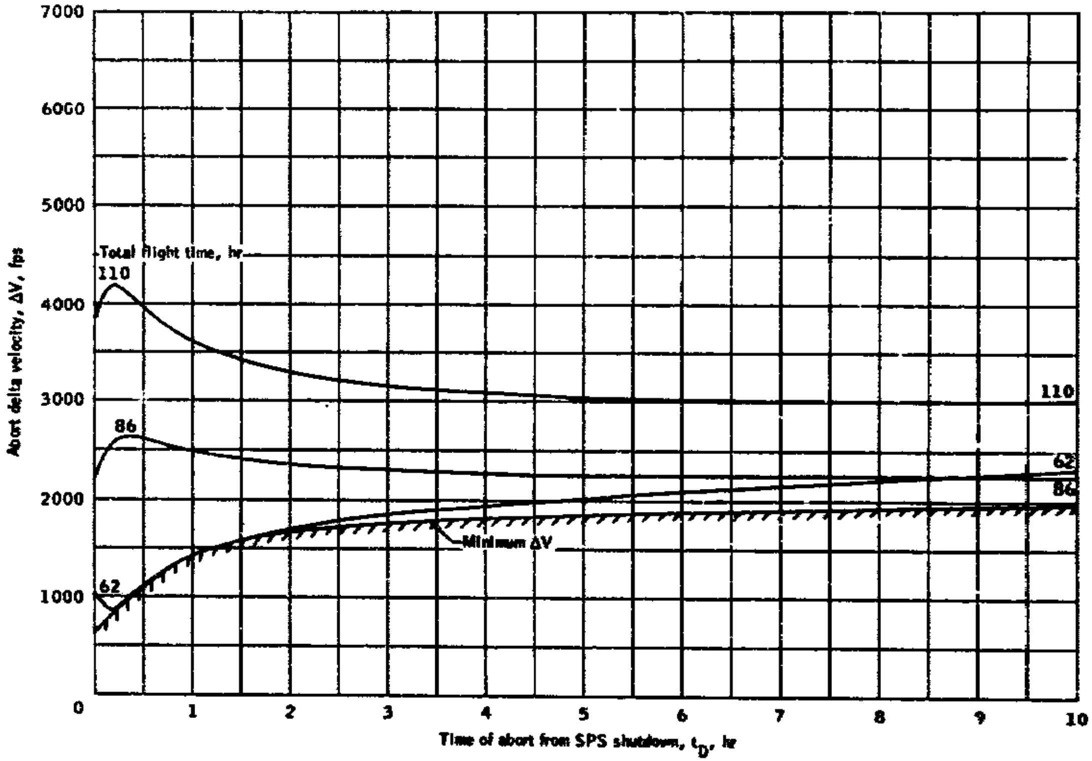
(c) Abort ΔV as a function of delay time from LOI shutdown (EPL).

Figure 8-9.- Continued.



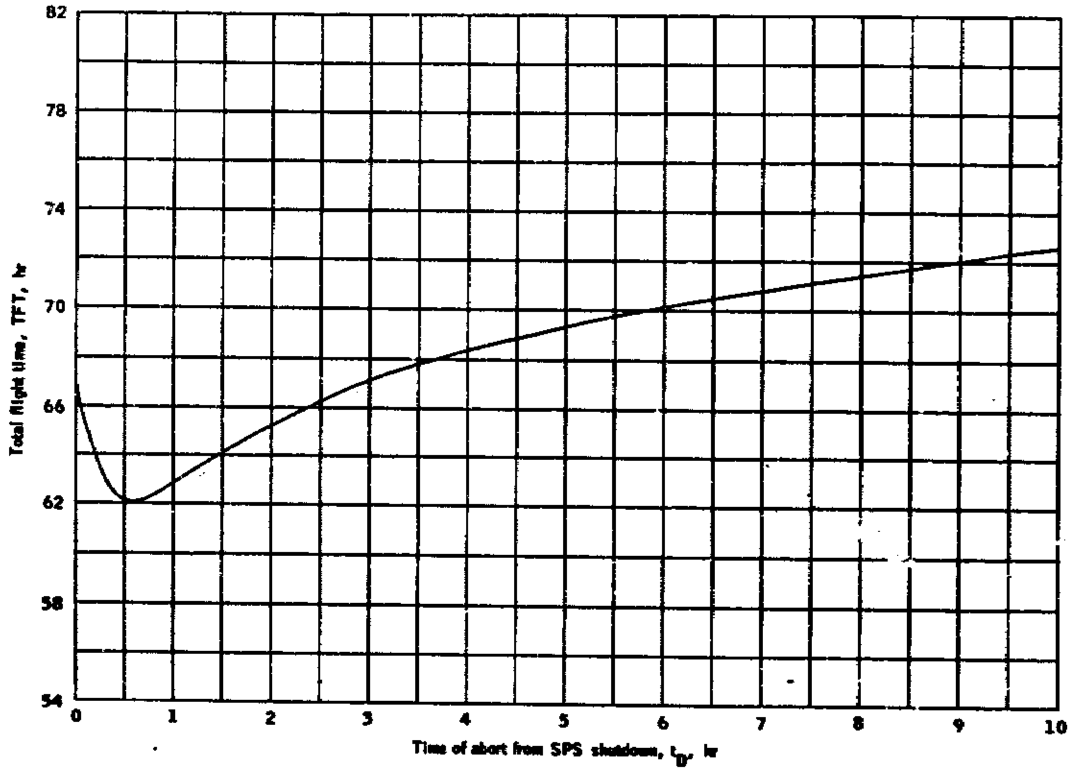
(d) Abort ΔV as a function of delay time from LOI shutdown (WPL).

Figure 8-9.- Continued.



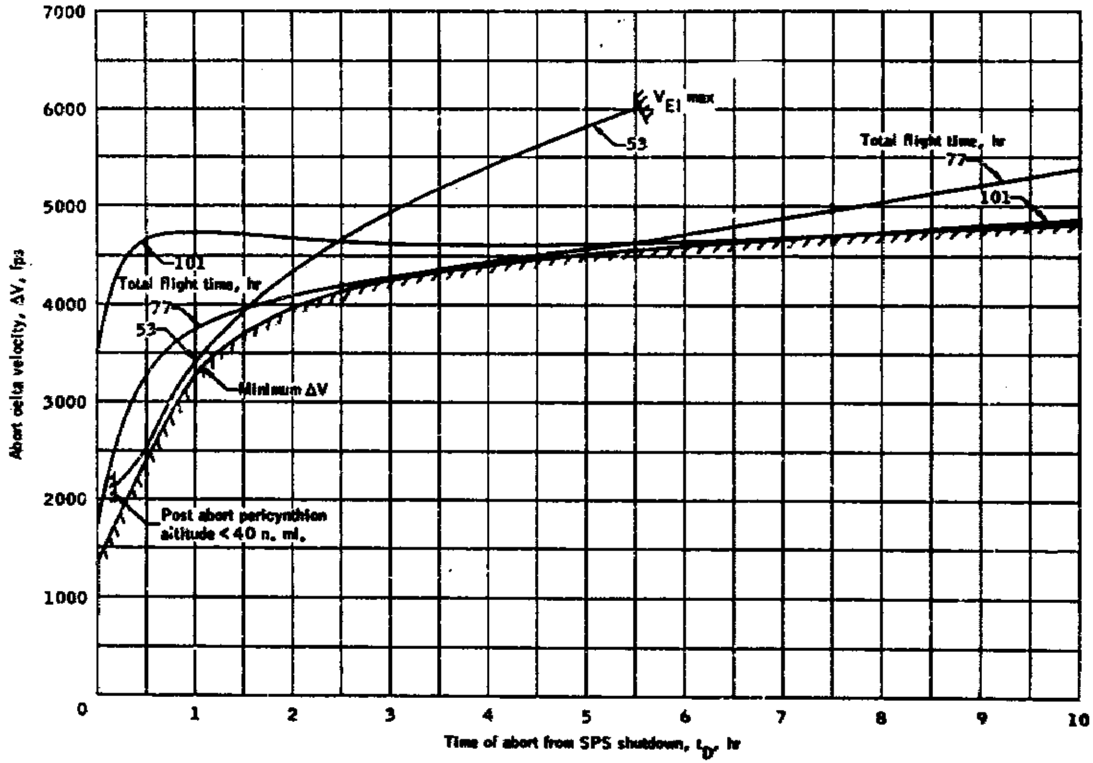
(e) Abort ΔV as a function of delay time from LOI shutdown (IOL).

Figure 8-9.- Continued.



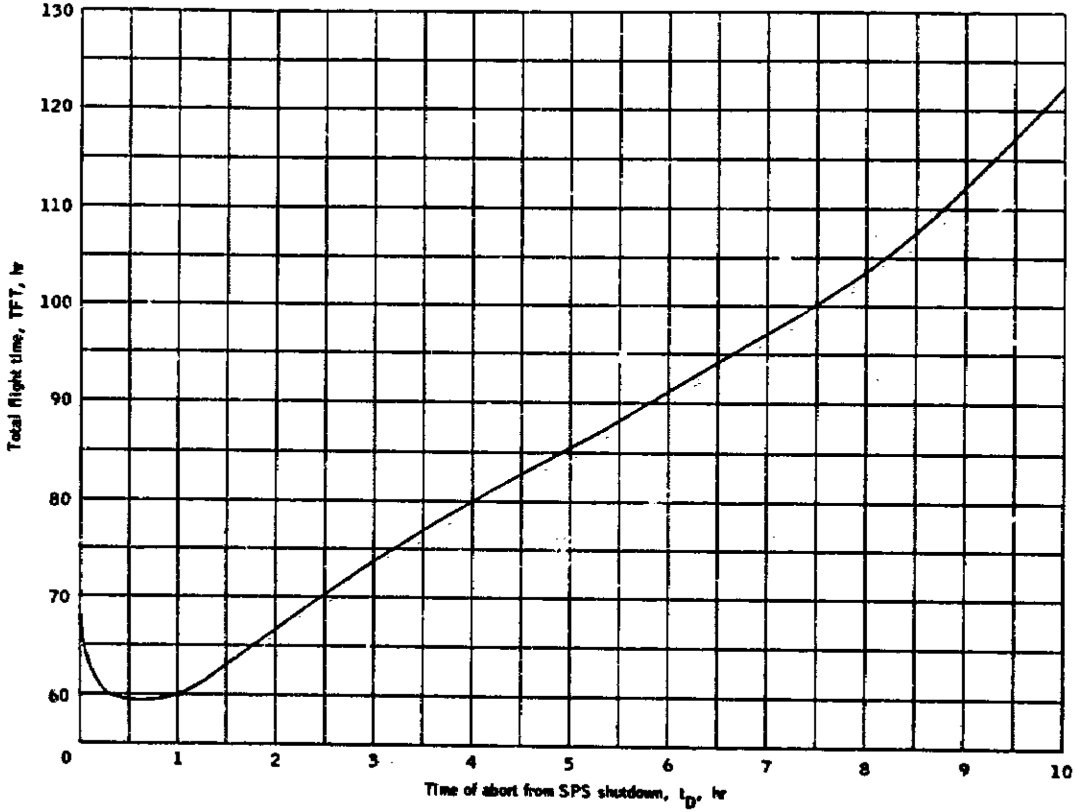
(f) Total flight time as a function of delay time for fuel critical unspecified area returns.

Figure 8-9.- Concluded.



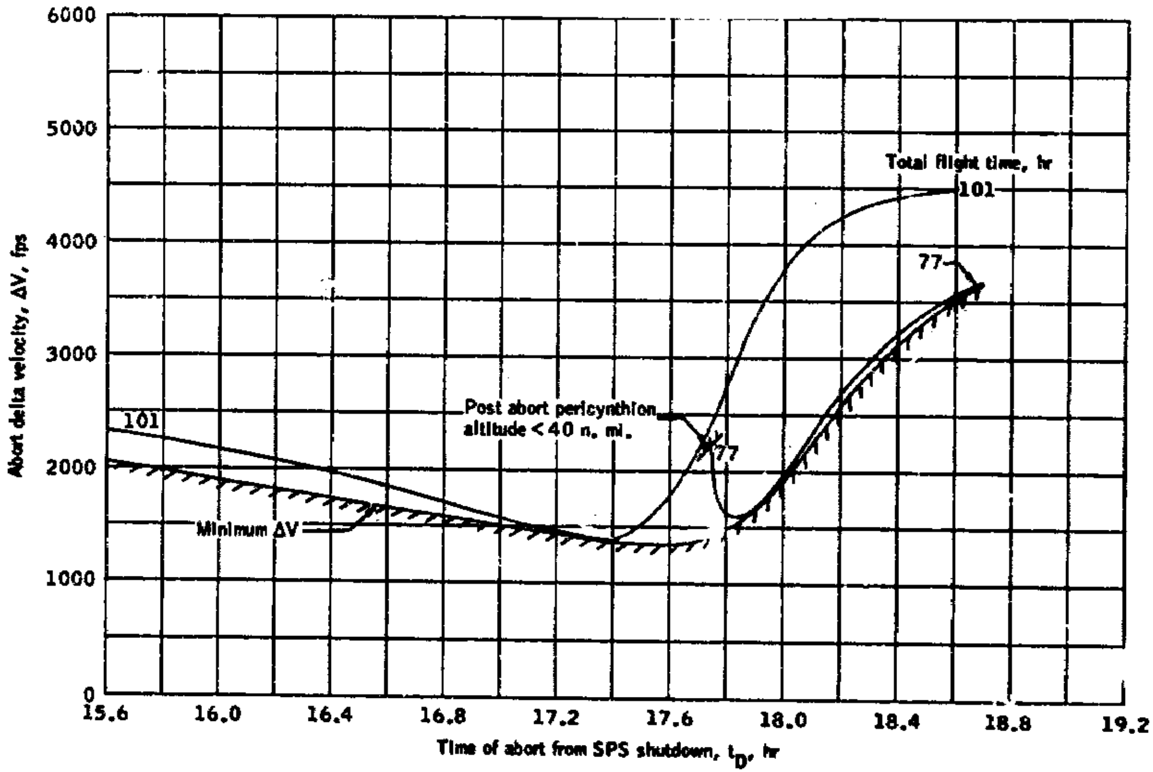
(a) Abort ΔV as a function of delay time from LOI shutdown, MPL and FCUA returns.

Figure 8-10.- Mode I abort analysis for LOI shutdown at 120 seconds.



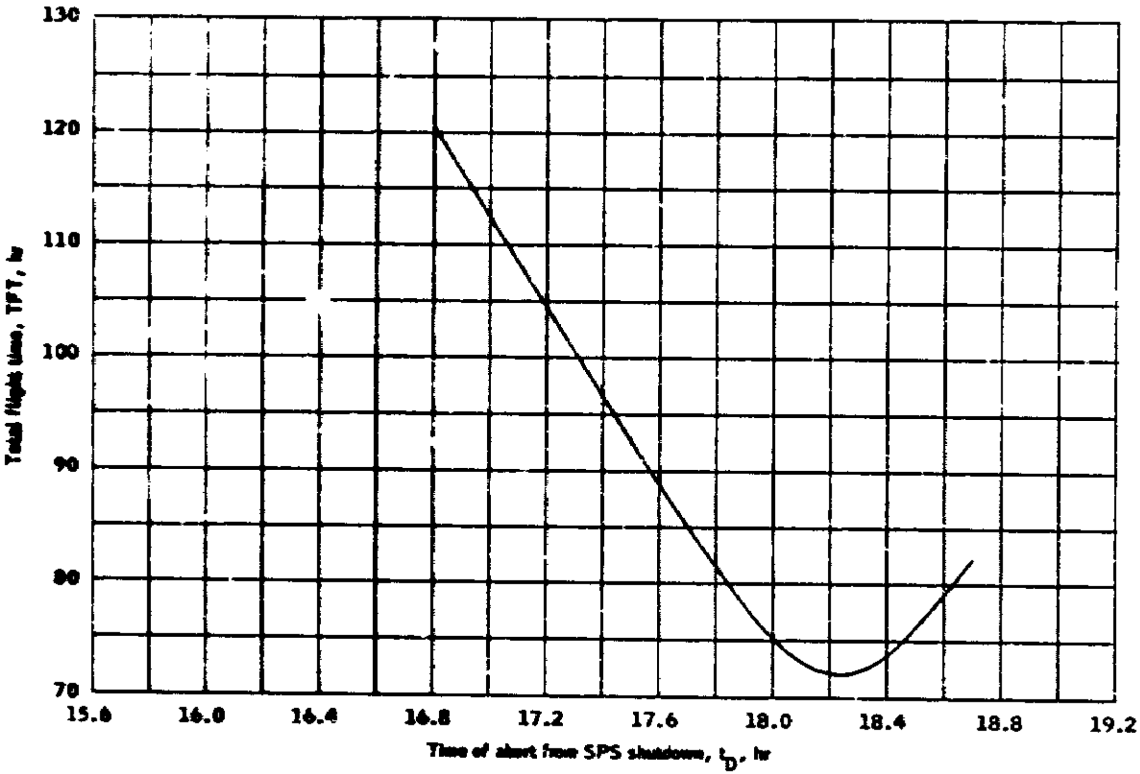
(b) Total flight time as a function of delay time from LOI shutdown, FCUA returns.

Figure 8-10.- Concluded.



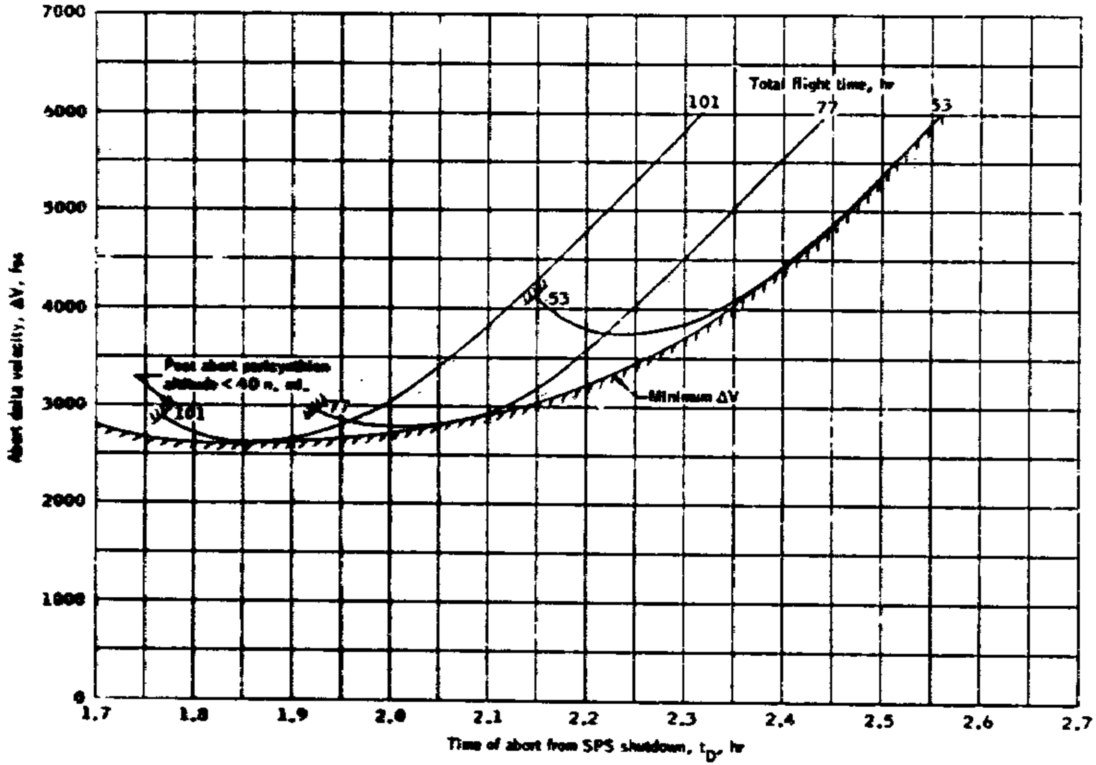
(a) Abort ΔV as a function of delay time from LOI shutdown, MPL and FCUA returns.

Figure 8-11.- Mode III abort analysis for LOI shutdown at 120 seconds.



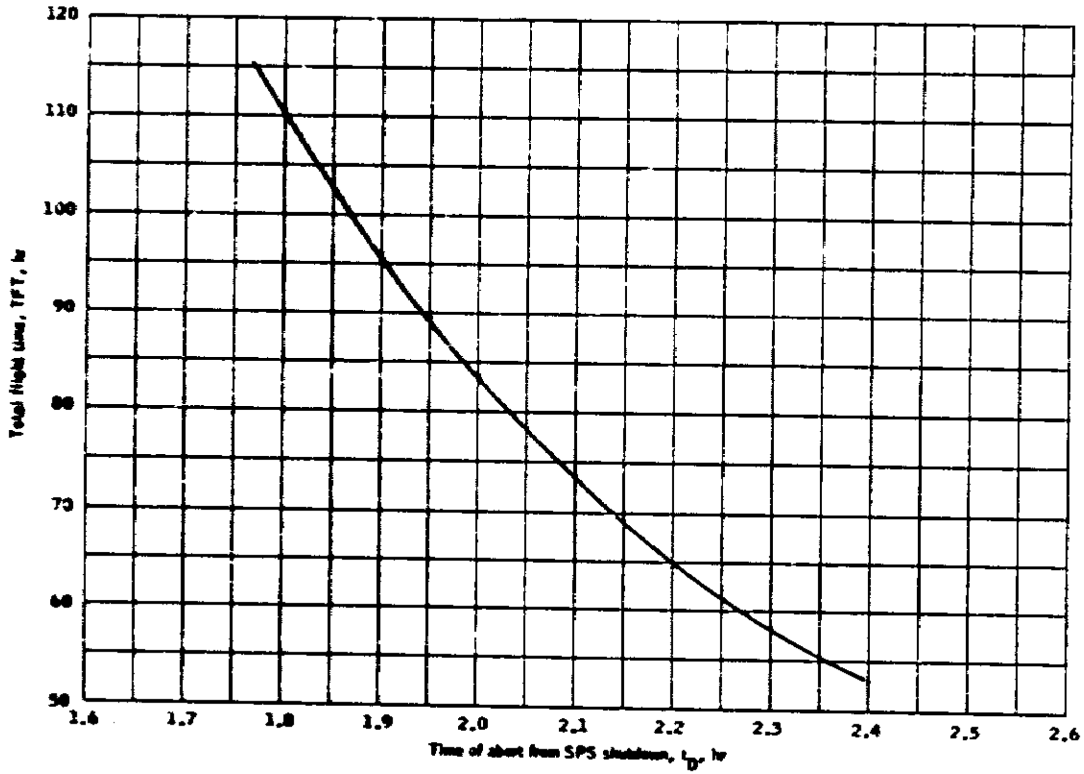
[illegible] Total flight time as a function of delay time from LOI shutdown, FCUA returns.

Figure 8-11.- Concluded.



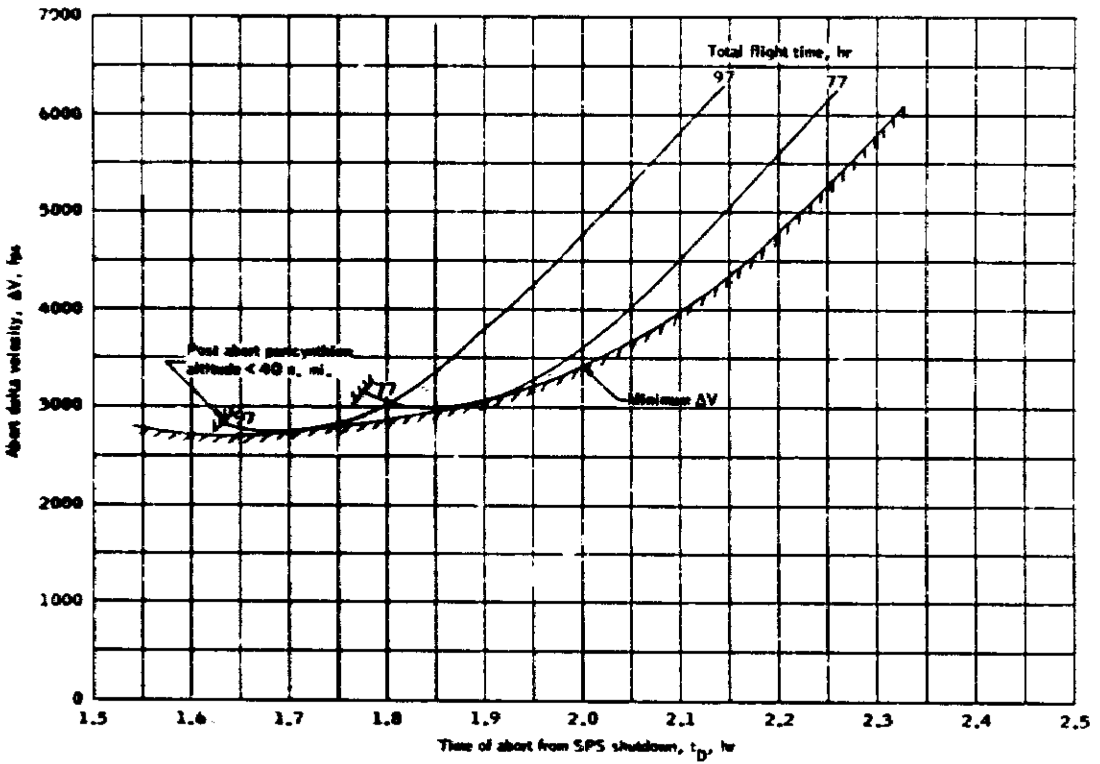
(a) Abort ΔV as a function of delay time from LOI shutdown, MPL and FCUA returns.

Figure 8-12.- Mode III abort analysis for nominal end of LOI(1) shutdown.



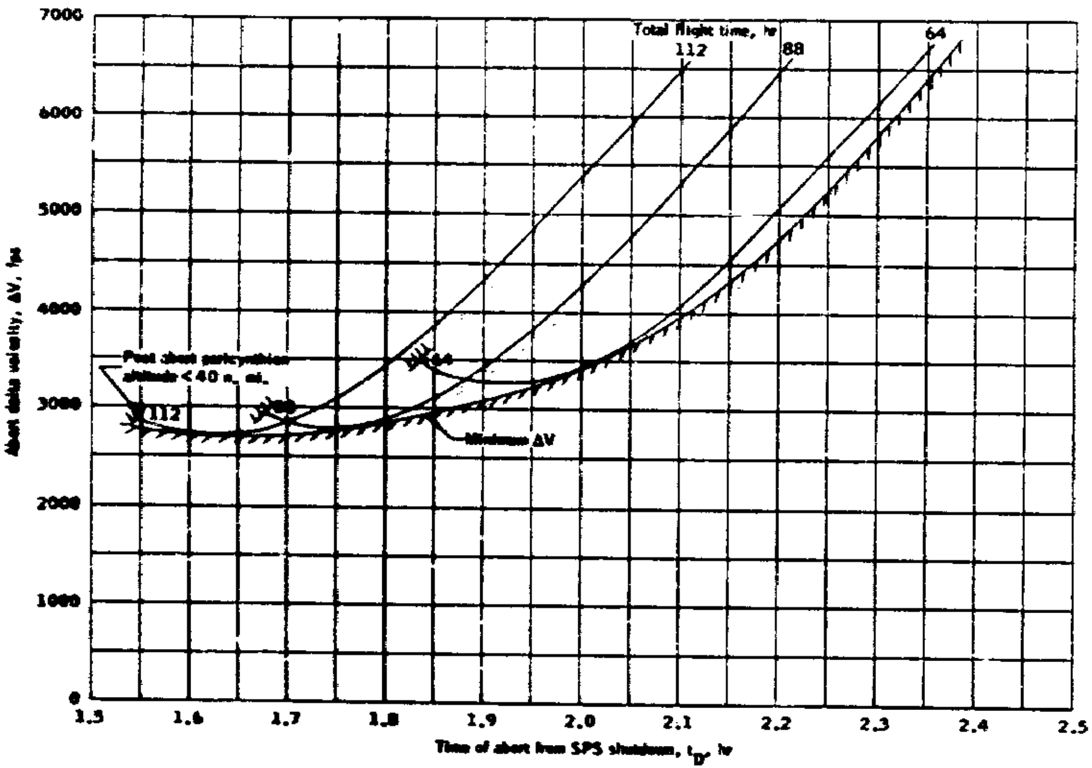
(b) Total flight time as a function of delay time from LOI shutdown, FCUA returns.

Figure 8-12.- Concluded.



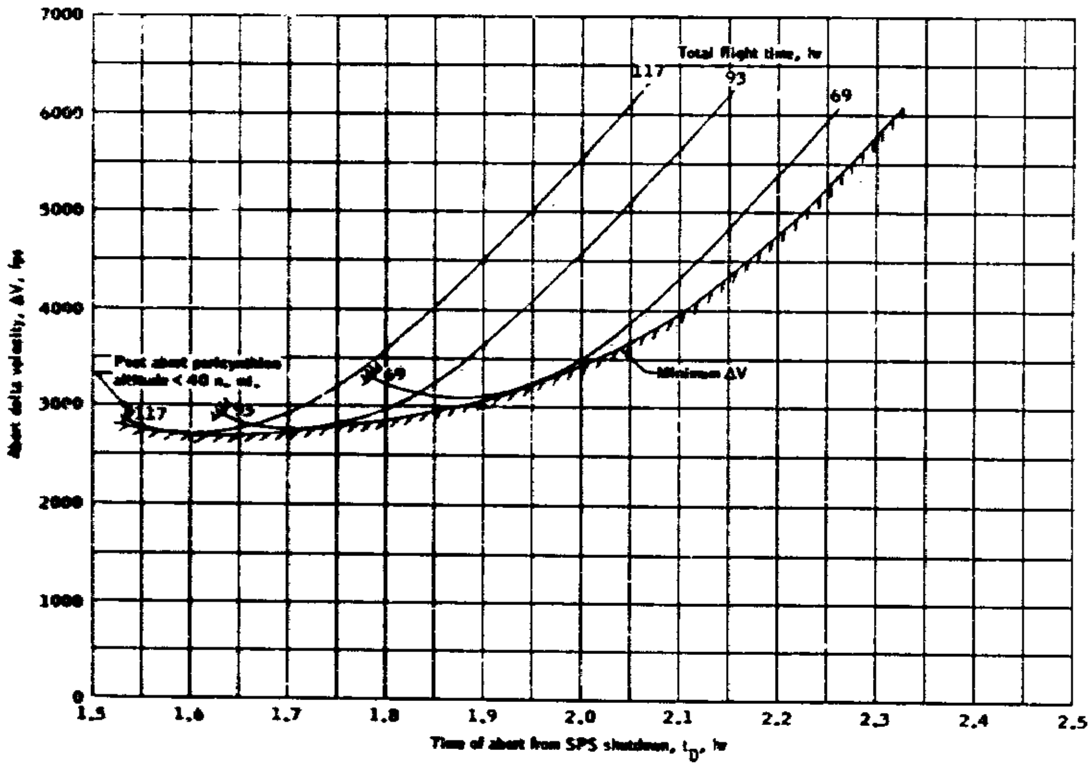
(a) Abort ΔV as a function of delay time from LOI shutdown (MPL and FCUA returns).

Figure 8-13.- Mode III abort analysis for nominal end of LOI(2) shutdown.



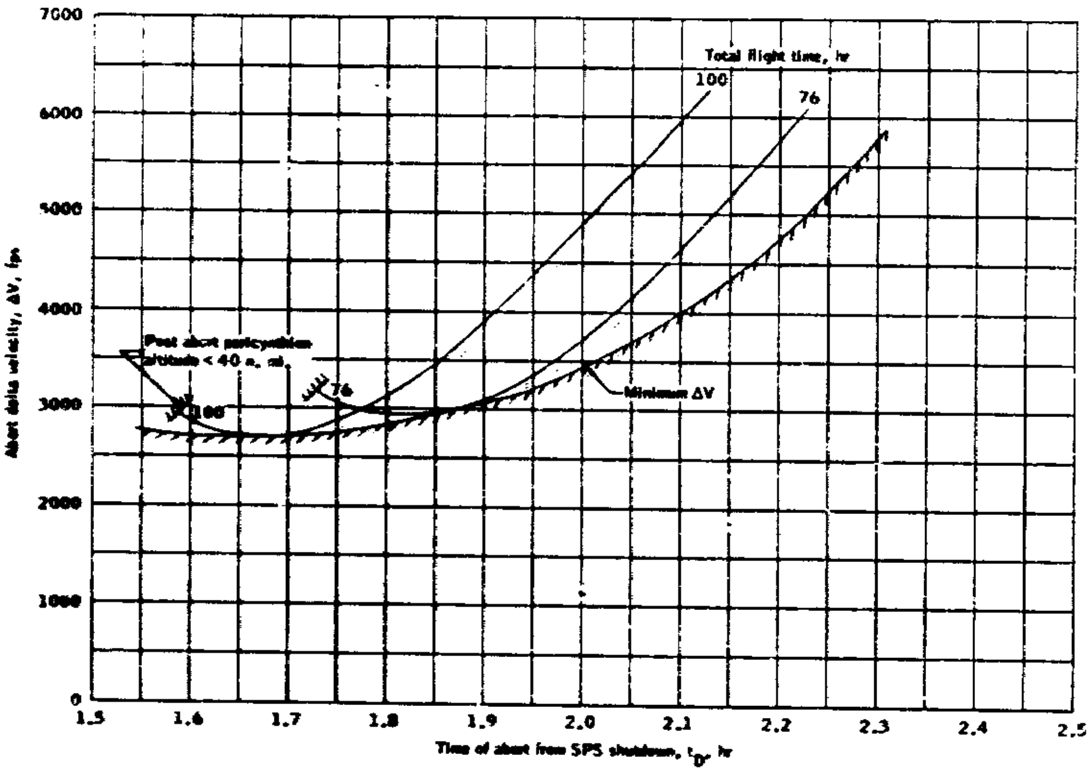
(b) Abort ΔV as a function of delay time from LOI shutdown (AOL).

Figure 8-13.- Continued.



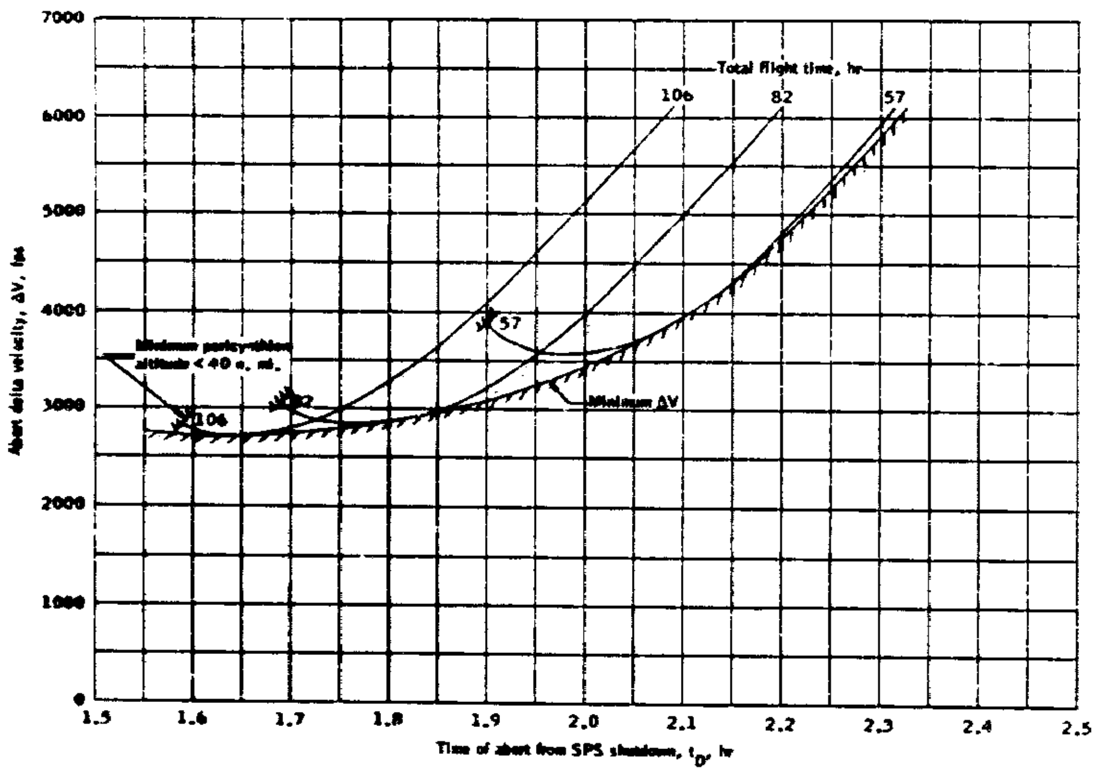
(c) Abort ΔV as a function of delay time from LOI shutdown (EPL).

Figure 8-13.- Continued.



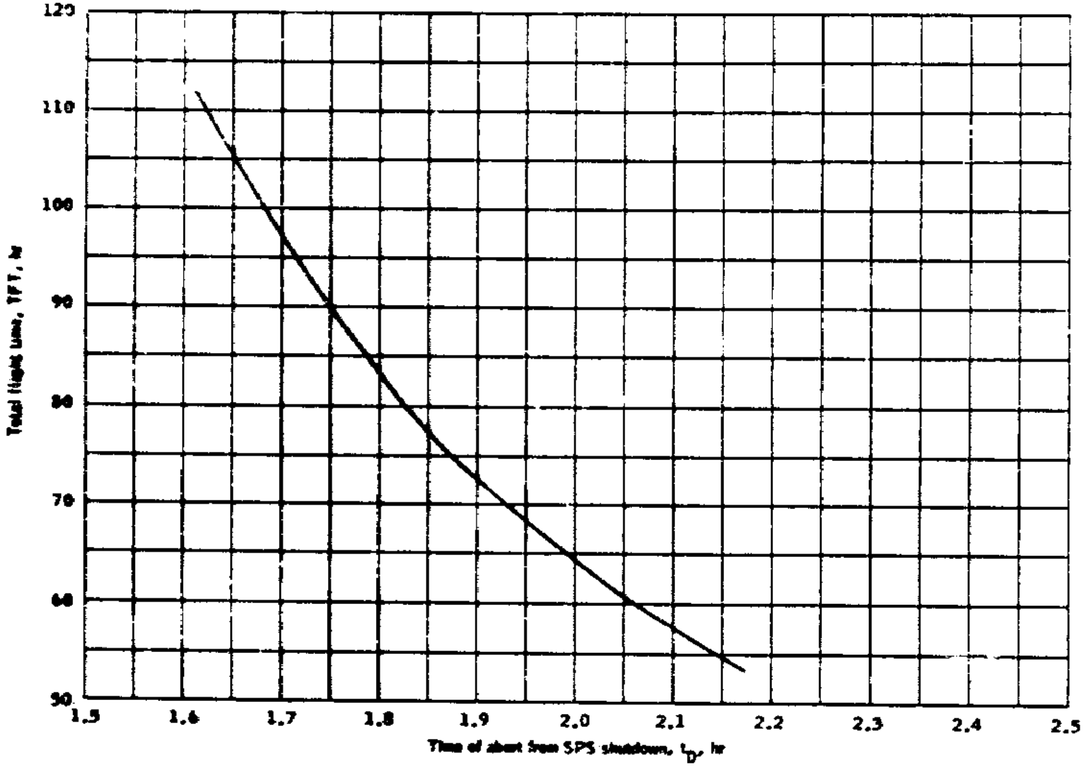
(d) Abort ΔV as a function of delay time from LOI shutdown (WPL).

Figure 8-13.- Continued.



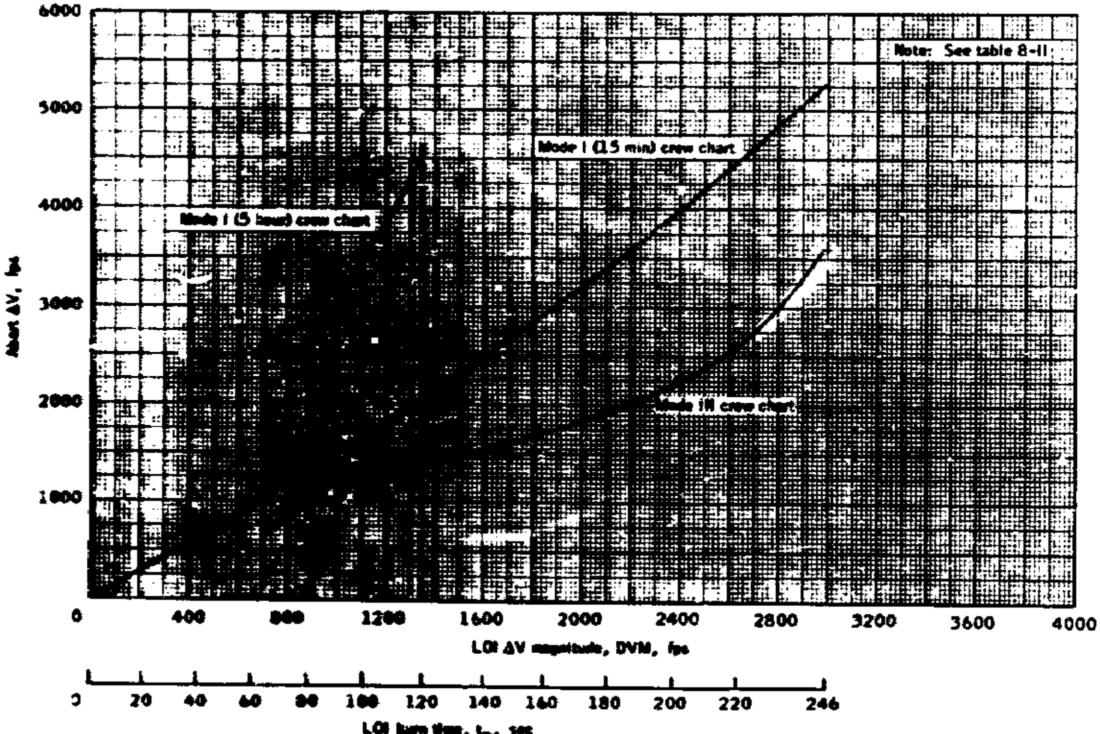
(a) Abort ΔV as a function of delay time from LOI shutdown (IOL).

Figure 8-15.- Continued.



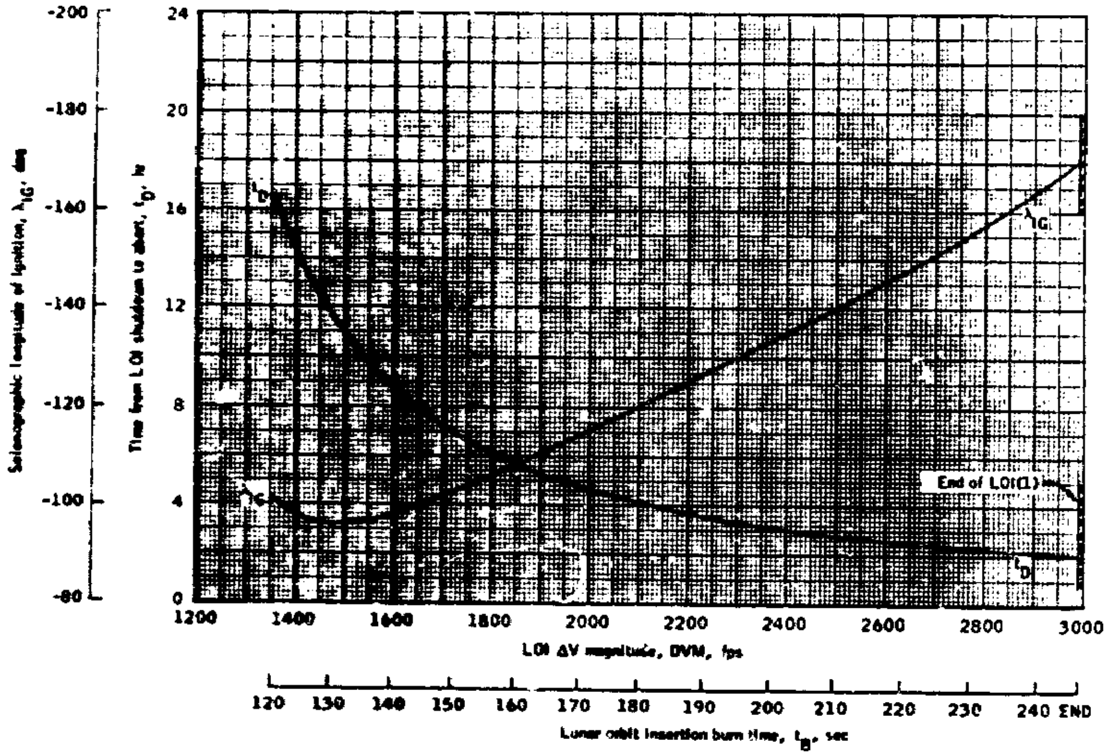
(f) Total flight time as a function of delay time for fuel critical unspecified area returns.

Figure 8-13.- Concluded.



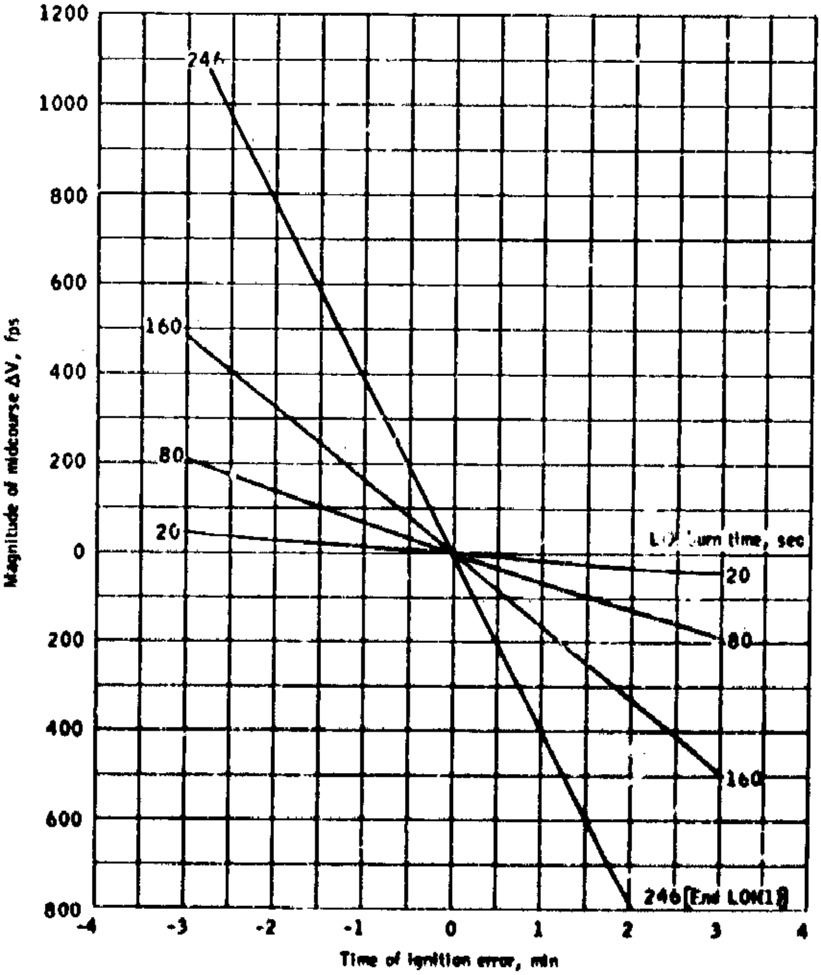
(a) Abort ΔV as a function of LOI ΔV magnitude for Mode I (15 minutes), Mode I (5 hours) and Mode III.

Figure 8-14.- Summary of LOI crew charts.



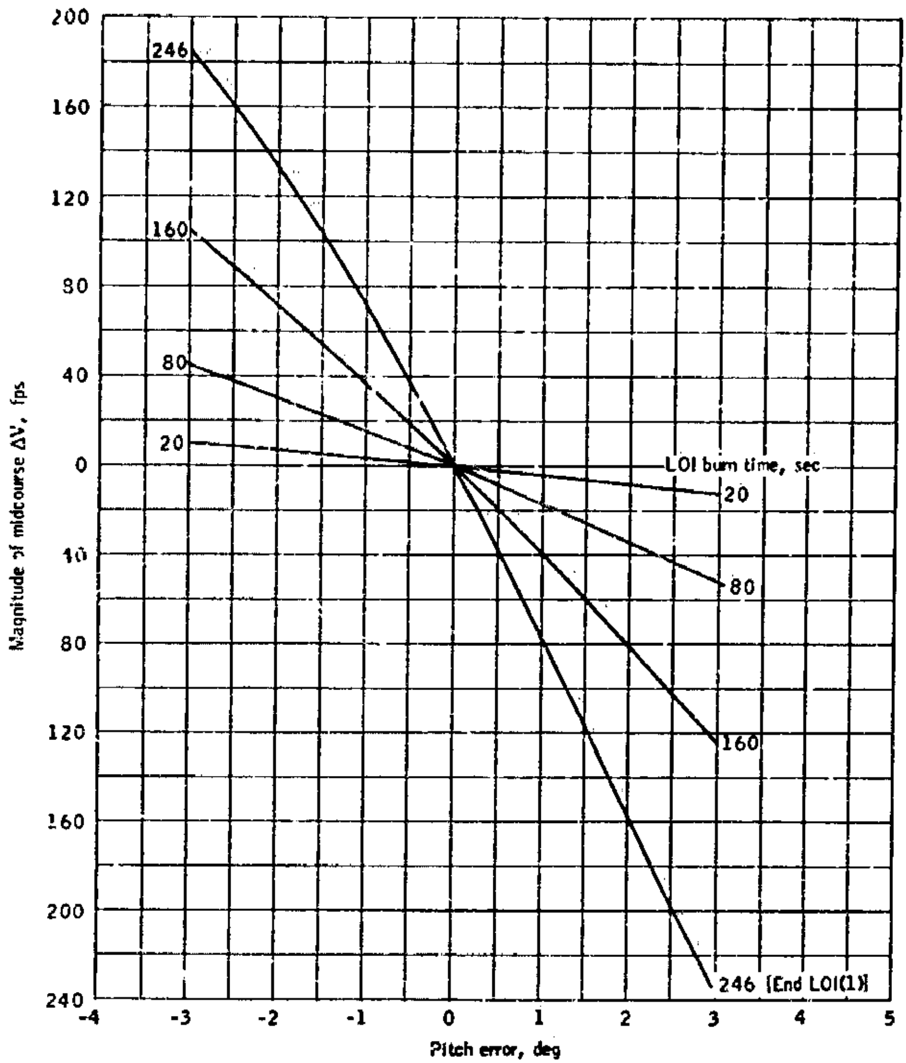
(b) Mode III time of ignition as a function of LOI ΔV magnitude.

Figure 8-14.- Concluded.



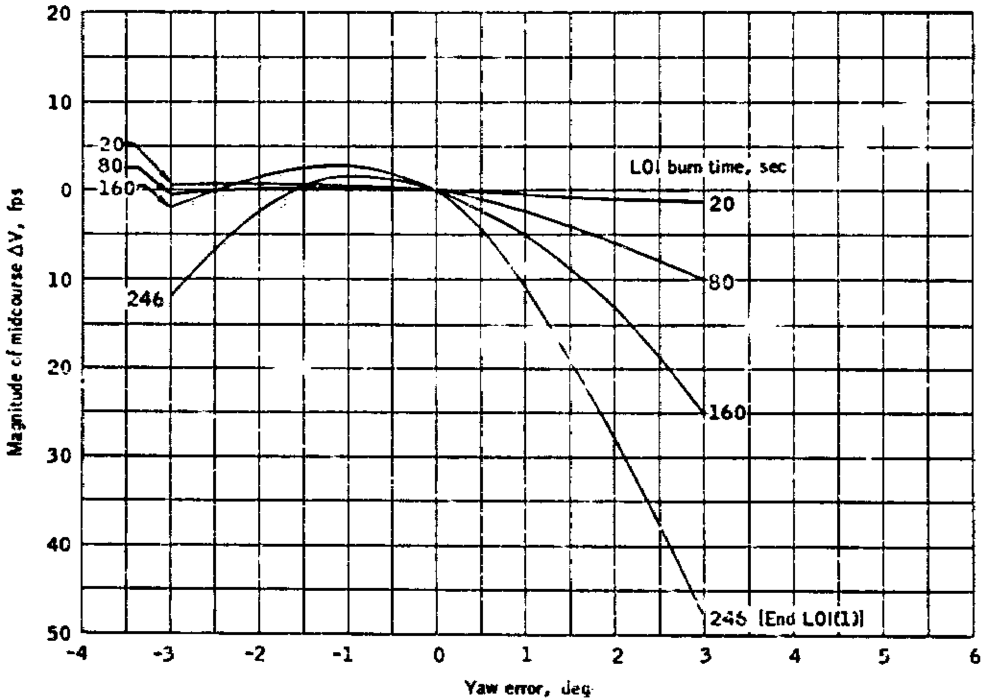
(a) MCC ΔV at MSI for ignition time errors.

Figure 8-15.- Mode I (15 minute) crew chart midcourse requirements.



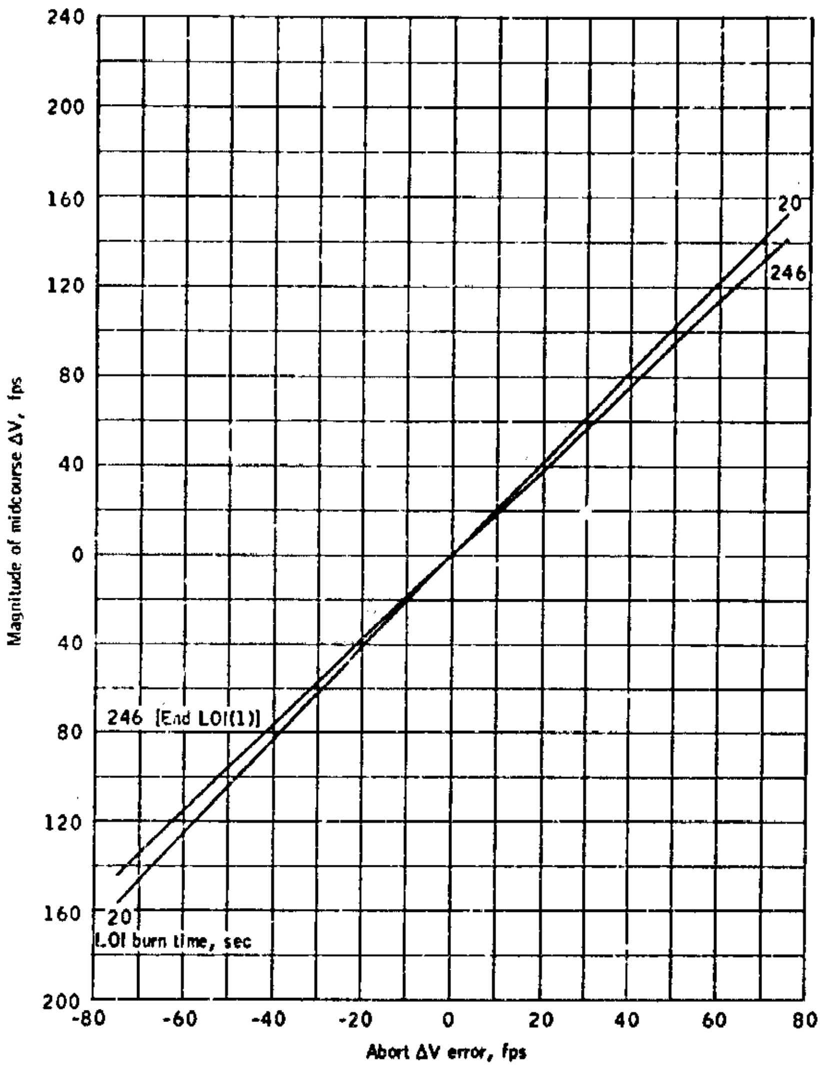
(b) MCC ΔV at MSI for pitch errors.

Figure 8-15.- Continued.



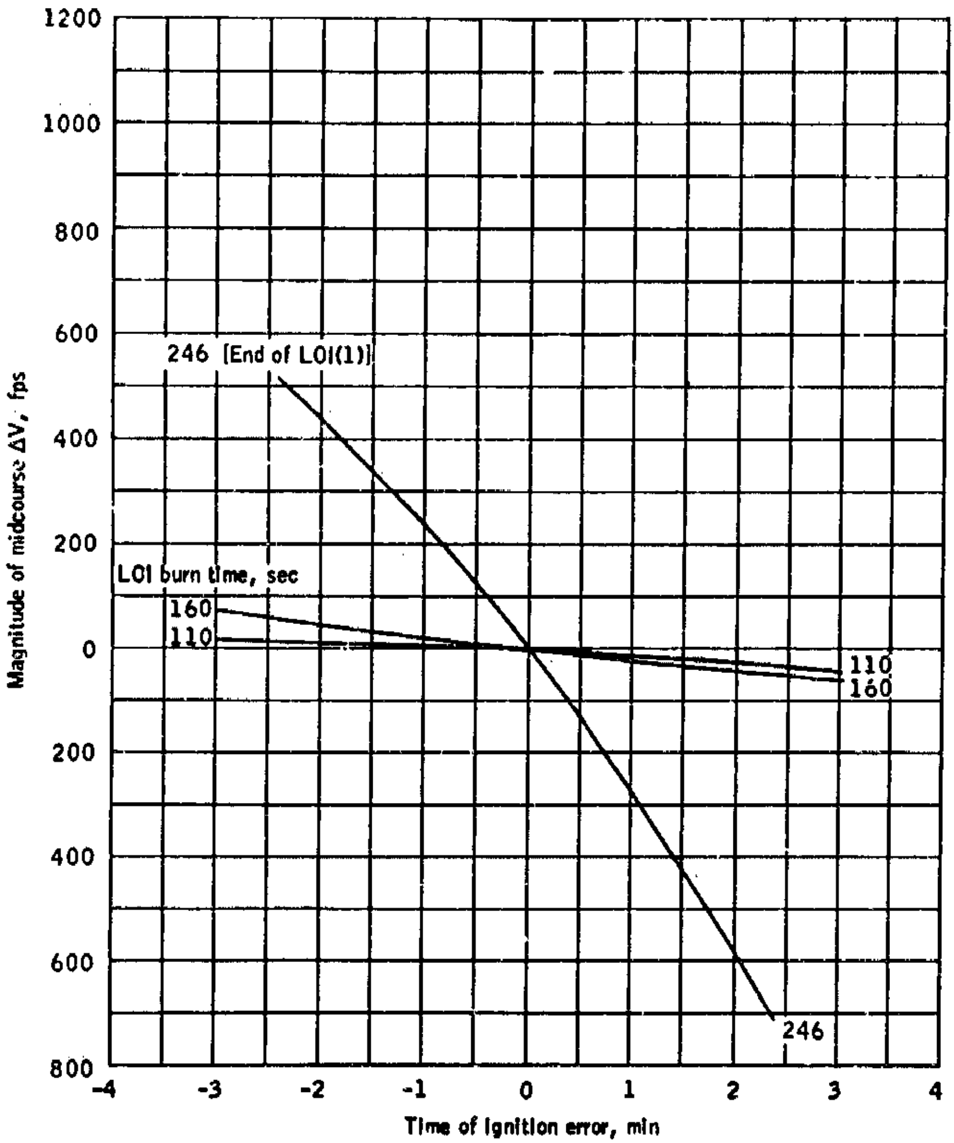
(c) MCC ΔV at MSI for yaw errors.

Figure 8-15.- Continued.



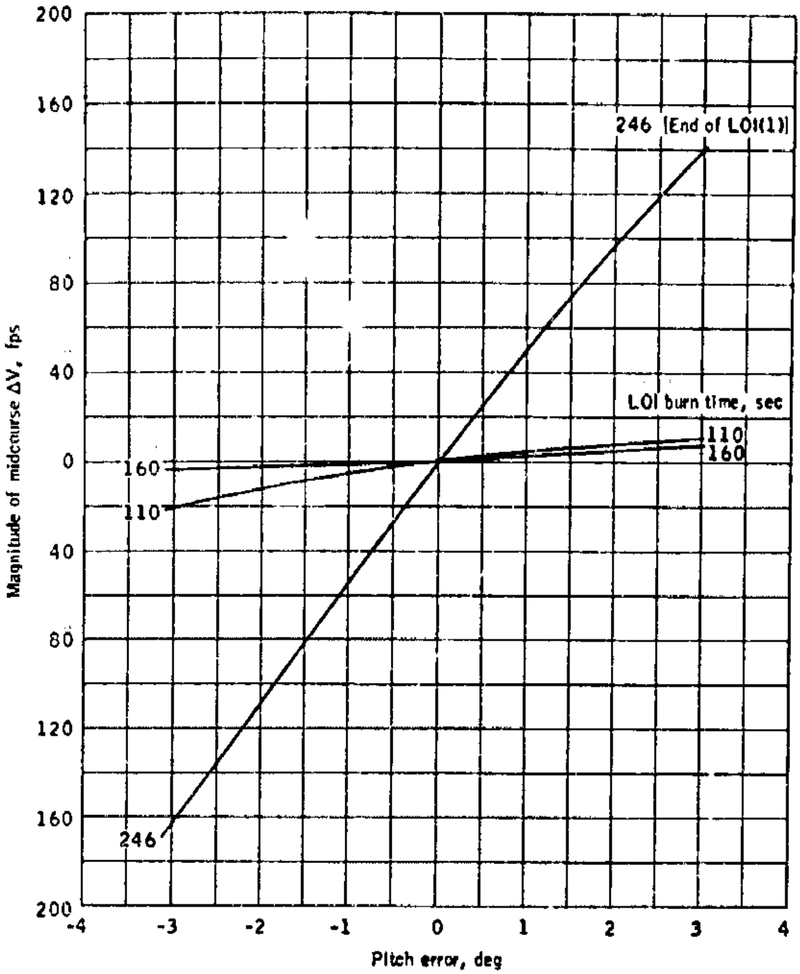
(d) MCC ΔV at MSI for abort ΔV errors.

Figure 8-15.- Concluded.



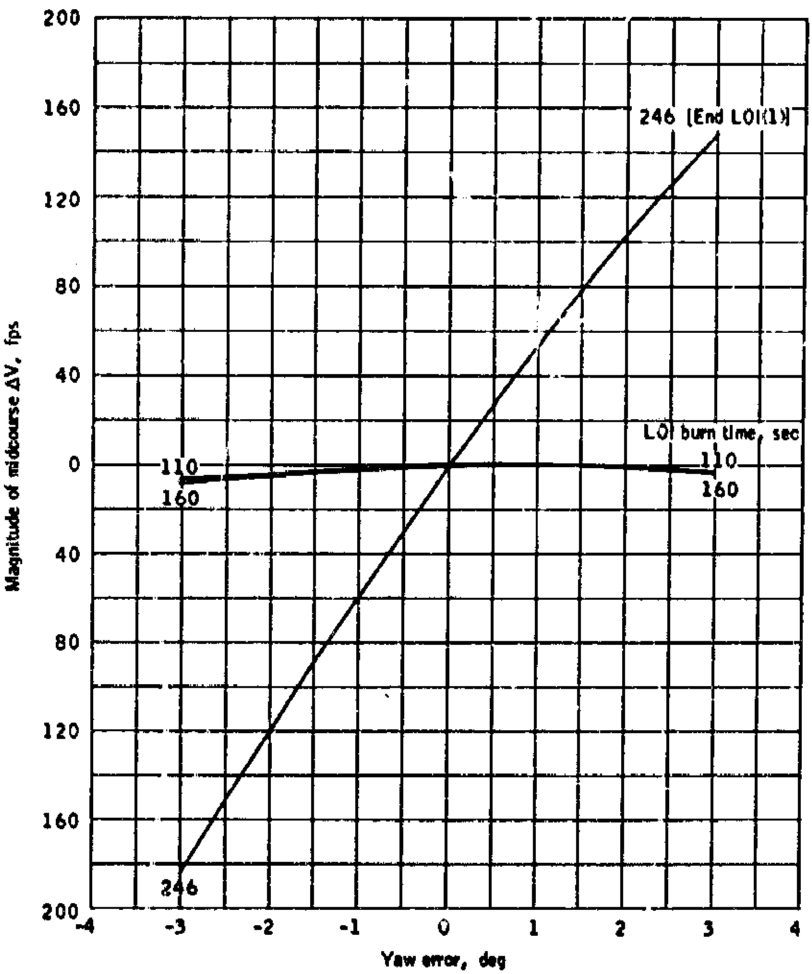
(a) MCC ΔV at MSI for ignition time errors.

Figure 8-16.- Mode III crew chart midcourse requirements.



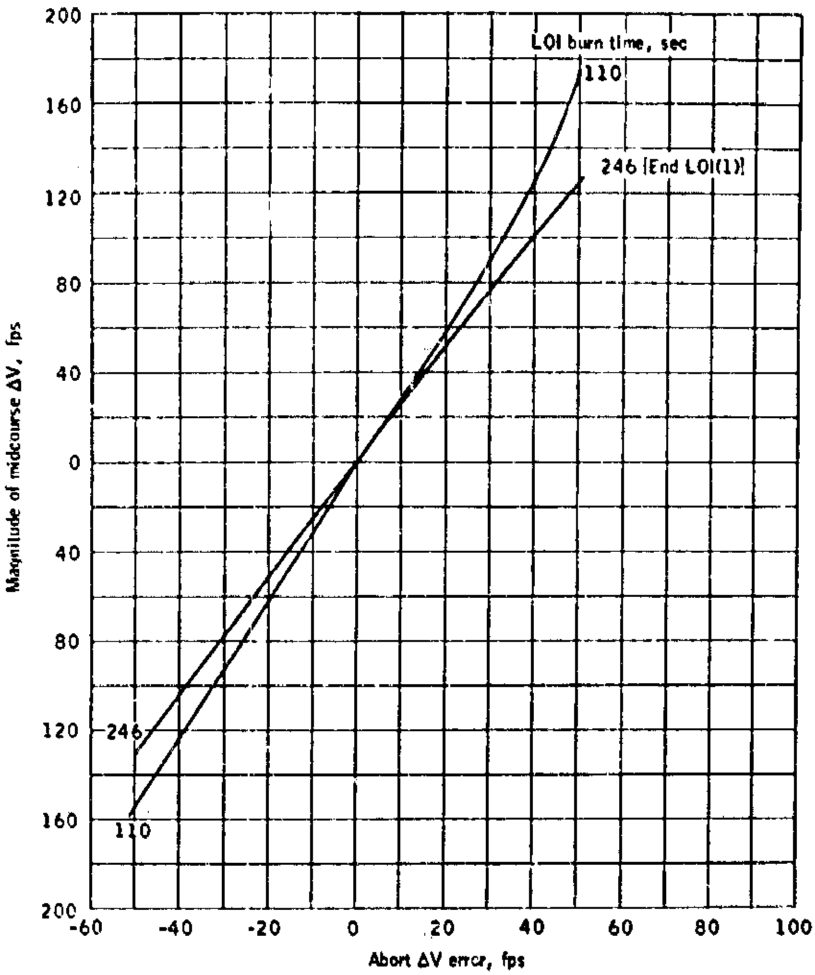
(b) MCC ΔV at MSI for pitch errors.

Figure 8-16.- Continued.



(c) MCC ΔV at MSI for yaw errors.

Figure 8-16.- Continued.



(d) MCC ΔV at MSI for abort ΔV errors.

Figure 8-16.- Concluded.

TRANSEARTH INJECTION AND
TRANSEARTH COAST PHASE

9.0 TRANSEARTH INJECTION AND TRANSEARTH COAST PHASE

9.1 Transearth Injection Monitoring

Like LOI, TEI occurs behind the moon and the monitoring procedures and techniques are basically the same. The major difference is that guidance, control, and system problems will all require a continuation of the maneuver. That is, guidance and control problems result in crew takeover and burn completion at the ignition attitude, whereas SPS or spacecraft system problems are ignored until this important maneuver is completed. A backup to the PGNCS TEI cutoff will be performed by the crew at 3 seconds past nominal time, and confirmation of achieving the desired cutoff velocity will be shown by the EMS ΔV counter. Inadvertent shutdowns during TEI will be restarted if possible within about 30 seconds or a ground solution will be required for a later abort attempt. Since abort targeting implies severe SPS problems and a communications failure would be required before an onboard backup is needed, the extensive preflight effort to generate TEI crew charts is unwarranted.

Manual takeover of the TEI maneuver will occur when, as in LOI, the crew confirms a deviation from the fixed inertial burn attitude by two independent references. A rate limit of 10 deg/sec will require immediate takeover, rate damping, and burn completion. The attitude deviation limit was selected with the aid of figure 9-1, which shows the MCC required for maneuvers controlled by a drifting PGNCS platform. It is seen that a drift which produces a 10° attitude change by the end of the 170-second maneuver requires an MCC of about 140 fps. The RCS capability at this point in the mission is approximately 200 fps, which allows some margin. As noted in section 8.1 (LOI Monitoring), this criteria for TEI was used to establish takeover limits, and for simplicity is used for LOI as well.

Effects of IMU platform pitch misalignments and drifts through TEI are shown in figure 9-2.

For consistency, any SPS abort maneuver will be made with the identical procedures used during TEI. This is in keeping with the time-critical nature of execution of abort maneuvers. During TLC an abort using up to 7000 fps may be required, whereas lunar phase aborts generally require about 3000 fps. Even though the takeover limits previously described can result in large MCC's, smaller limits will probably still require an SPS MCC. Also, the simplicity of having one monitoring procedure for all SPS burns is an important consideration, especially for the flight crew.

9.2 Aborts During TEI and Transearth Coast

9.2.1 Introduction.- The TEI burn transfers the spacecraft from the 60- by 60-n. mi. altitude LPO to the TEC. The transfer consists of a single SPS burn of approximately 171 seconds and imparts a ΔV of [illegible]40 fps.

Reiterating the philosophy of TEI burn monitoring, completion of the TEI burn is mandatory. That is, a manual shutdown will not be initiated for any CSM systems problem. If an early automatic SPS shutdown occurs, an immediate restart will be attempted. Only if immediate reignition is not possible will an RTCC abort solution be required. Therefore, since abort targeting implies severe SPS problems, and an additional failure of communications would be required before an onboard backup is needed, the extensive preflight effort to generate TEI crew charts is unwarranted.

In the following paragraphs, general parametric data of abort ΔV and total flight times are included to illustrate the possible tradeoffs that can be made in the final selection of the RTCC abort solution.

9.2.2 Characteristics of lunar trajectories resulting from premature TEI shutdowns.- The description of the three classes of trajectories made in section 8.2.2 applies here, with the exception of the respective TEI burn times:

1. Class III - TEI ignition to 120 seconds.

2. Class II - 120 seconds to 138 seconds.

3. Class I - 138 seconds to nominal TEI shutdown.

Figure 9-3 shows the conic parameters at TEI shutdown as a function of SPS burn time.

9.2.3 Abort modes.- The description of the lunar phase abort maneuvers in section 8.2.3 again applies here. Figure 9-4 shows the abort mode overlap that exists for the C' mission. Note that a mode III abort is available prior to 120 seconds of TEI burn. The range of TEI shutdowns for which a mode I abort is possible is a function of the abort ΔV available and the delay time to abort initiation. Figure 9-5 shows the SPS ΔV available following a premature SPS shutdown during the TEI burn.

9.2.4 Abort ground rules.- If an automatic SPS shutdown occurs prematurely and an immediate SPS reignition is not possible, the following abort criteria will be followed:

1. If a nonimpacting pericynthion still exists (TEI burn time < 120 seconds), a mode III RTCC abort will be initiated.

2. If a nonimpacting pericynthion no longer exists (TEI burn time > 120 seconds), a mode I abort will be initiated as soon as possible.

It was stated in the previous TEI discussion that crew charts are unwarranted since several CSM system failures must occur before they would be needed. However, an important onboard backup still available should be noted. Following a TEI burn in excess of 138 seconds, the spacecraft will exit the MSI. The onboard return-to-earth program (P-37) is now available to calculate the return-to-earth maneuver. The high ΔV requirements would be for a shutdown at 138 seconds since this is the lowest energy ellipse of the region. However, for this case the ΔV = 2400 fps and the TFT = 100 hours. This is well within the ΔV available of figure 9-5.

9.2.5 Parametric abort data as a function of TEI shutdown.- This section includes a brief description of the abort ΔV requirements for the abort solutions generated by the RTCC.

Figure 9-6(a) shows the minimum mode I abort ΔV for unspecified landing areas as a function of TEI burn time. Figure 9-6(b) indicates the corresponding total times from TEI shutdown to earth landing (TFT). The similarity of these figures as well as the mode I contingency landing area data Fig. 9-7(a), (b), and (c), to the previously discussed LOI data is evident. In addition, the mode III abort ΔV requirements for MPL and FCUA returns as a function of TEI burn time is presented in figure 9-8.

9.2.6 Abort analysis of specific TEI shutdowns.- Figure 9-9 presents the abort ΔV and TFT for mode I aborts following a premature TEI shutdown at 60 seconds (class III preabort trajectory). Data is included for MPL and FCUA returns. The comparable mode III abort solutions are presented in figure 9-10. As seen in previous figures, the mode III abort affords a significant reduction in abort ΔV over the mode I maneuver.

Figure 9-11 shows the abort ΔV and TFT associated with mode I FCUA and CLA's for TEI shutdown at 140 seconds (class I preabort trajectory). Returns to the MPL, AOL, EPL, WPL, and IOL are included.

9.2.7 Transearth coast aborts.- Aborts during the TEC would be initiated if a faster earth return is required than the nominal TEC. The amount of time the TEC can be reduced, however, is limited by the entry velocity restraints of the CM heat shield. This limit is 36 333 fps. Therefore, depending on where in the TEC the abort is initiated, only a small reduction in TEC flight time is afforded since the normal entry velocity for lunar returns is in the range of 36 100 to 36 200 fps.

The targeting for these abort maneuvers, as well as normal midcourse corrections to correct entry conditions, is provided by either the RTCC or, outside the MSI, the CMC P-37.

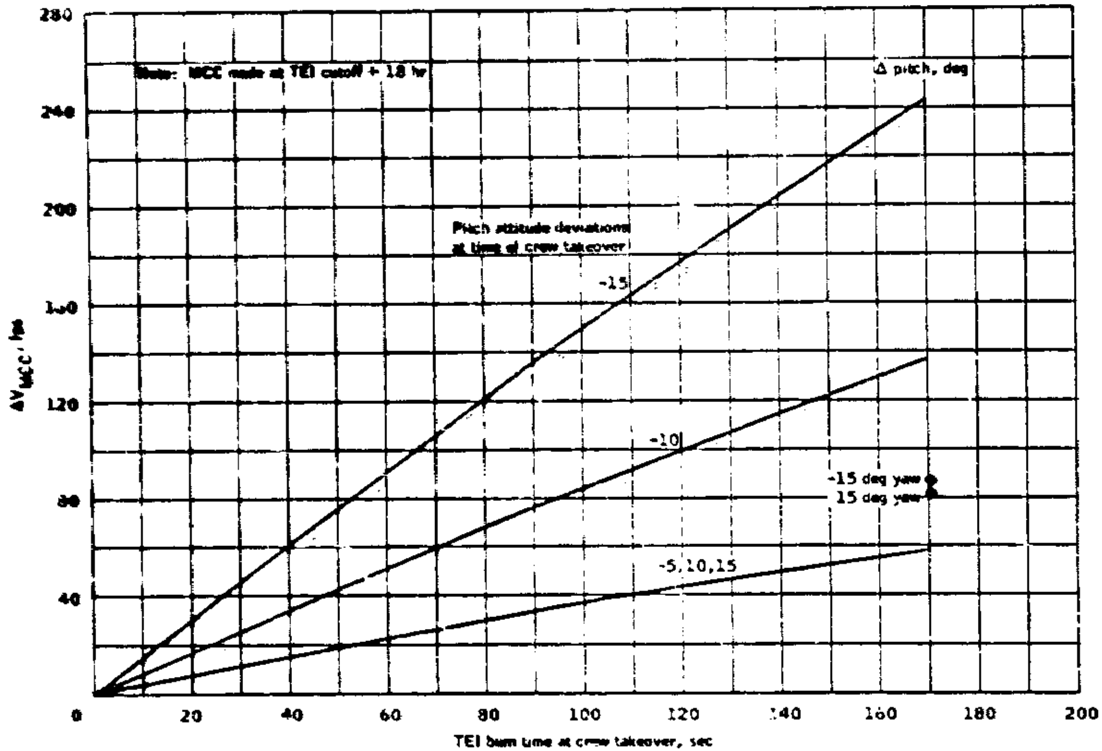


Figure 9-1.- Midcourse correction requirements for various attitude deviations during the TEI maneuver.

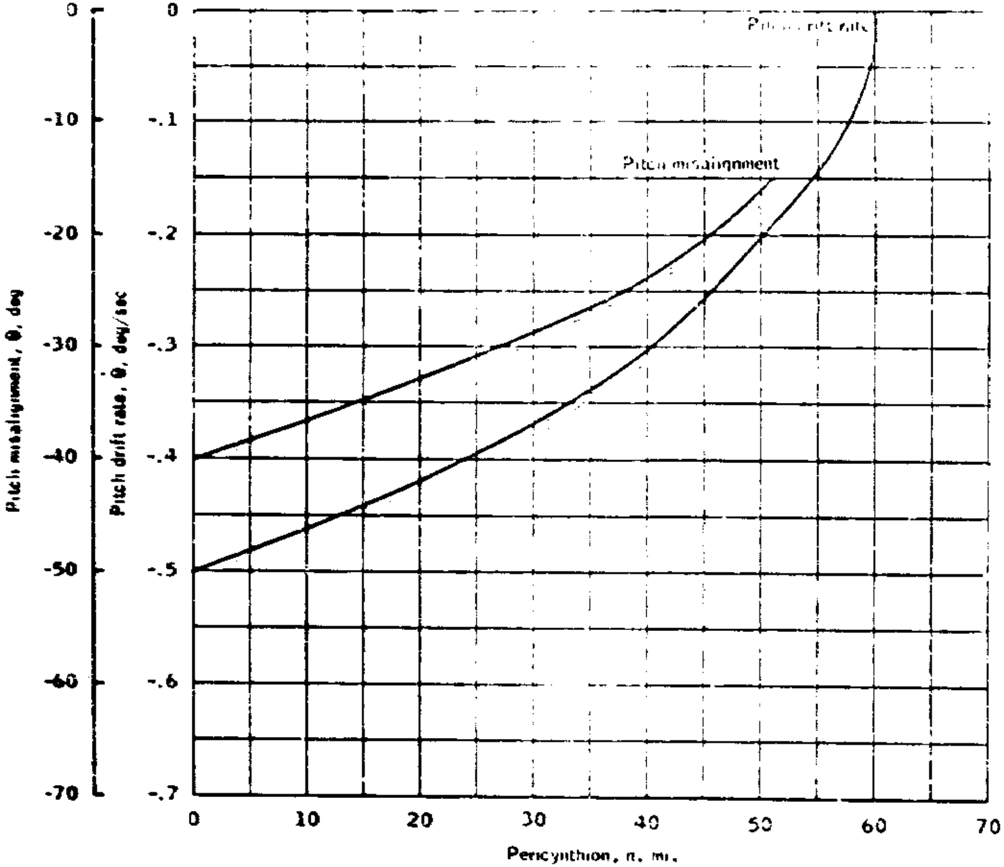


Figure 9-2.- Pericynthion altitude for simulated IMU pitch drifts and misalignments during TEI.

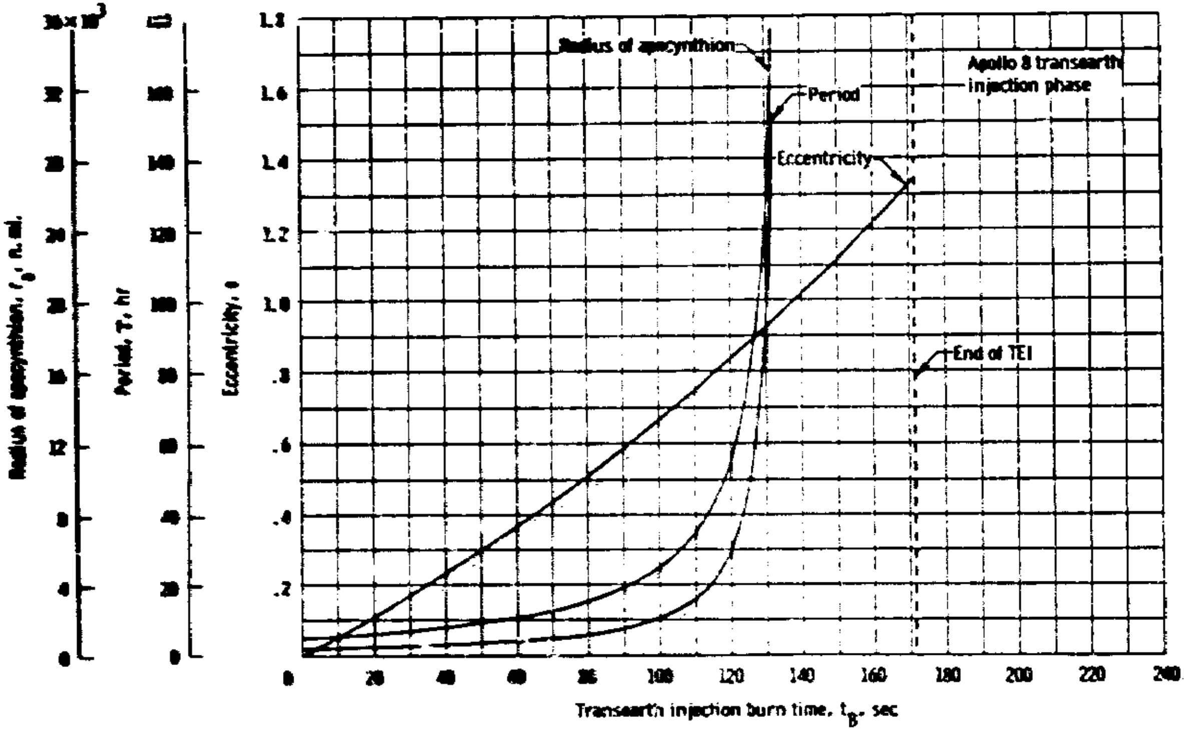


Figure 9-3.- Conic parameters as a function of SPS burn time during the transearth injection burn.

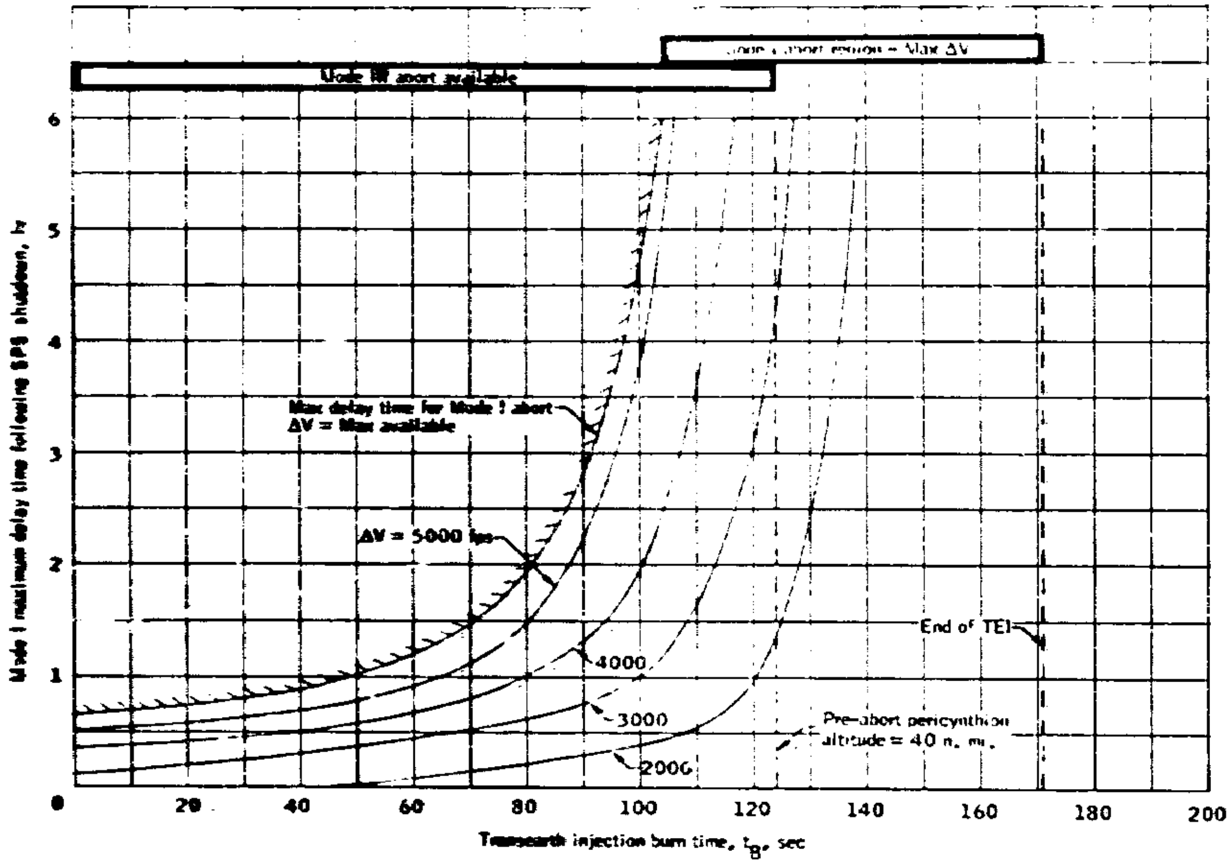


Figure 9-4.- Transearth injection abort mode overlap.

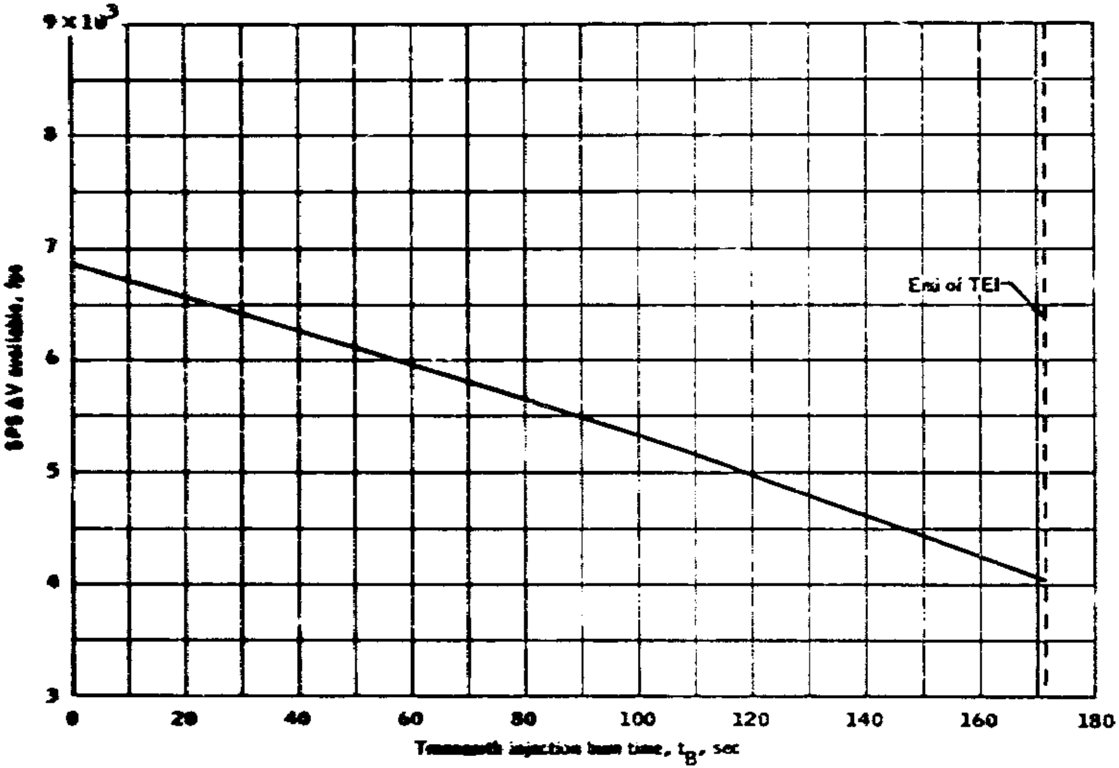
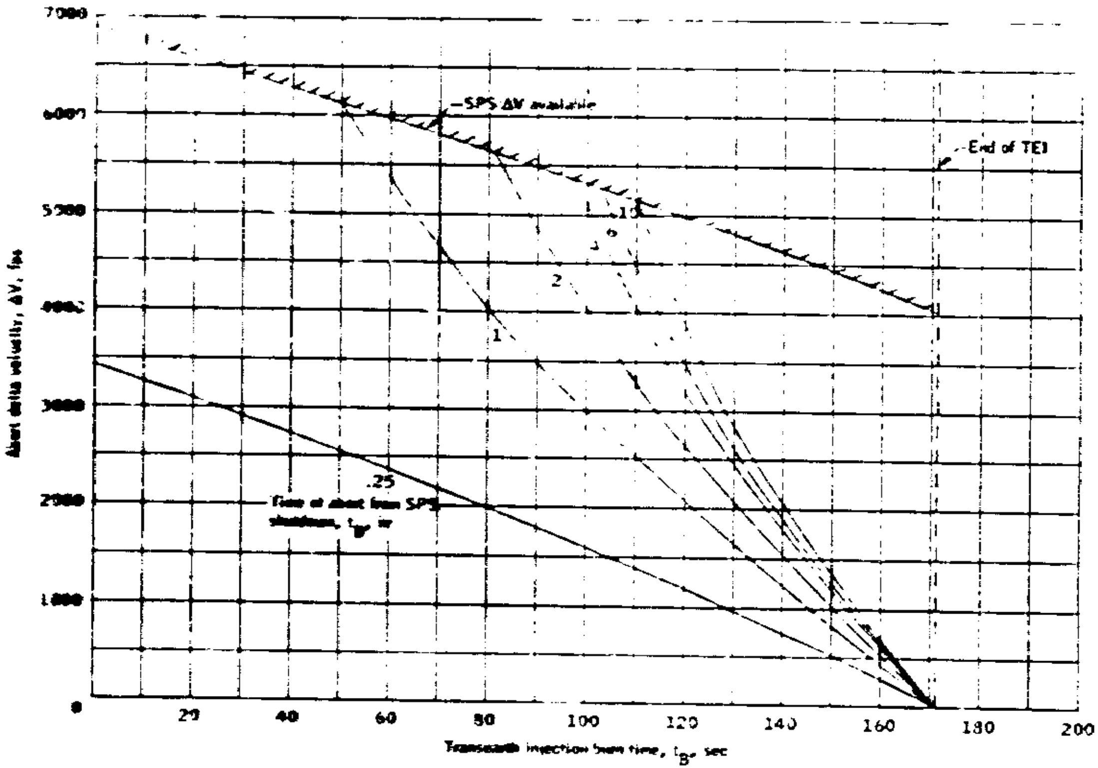
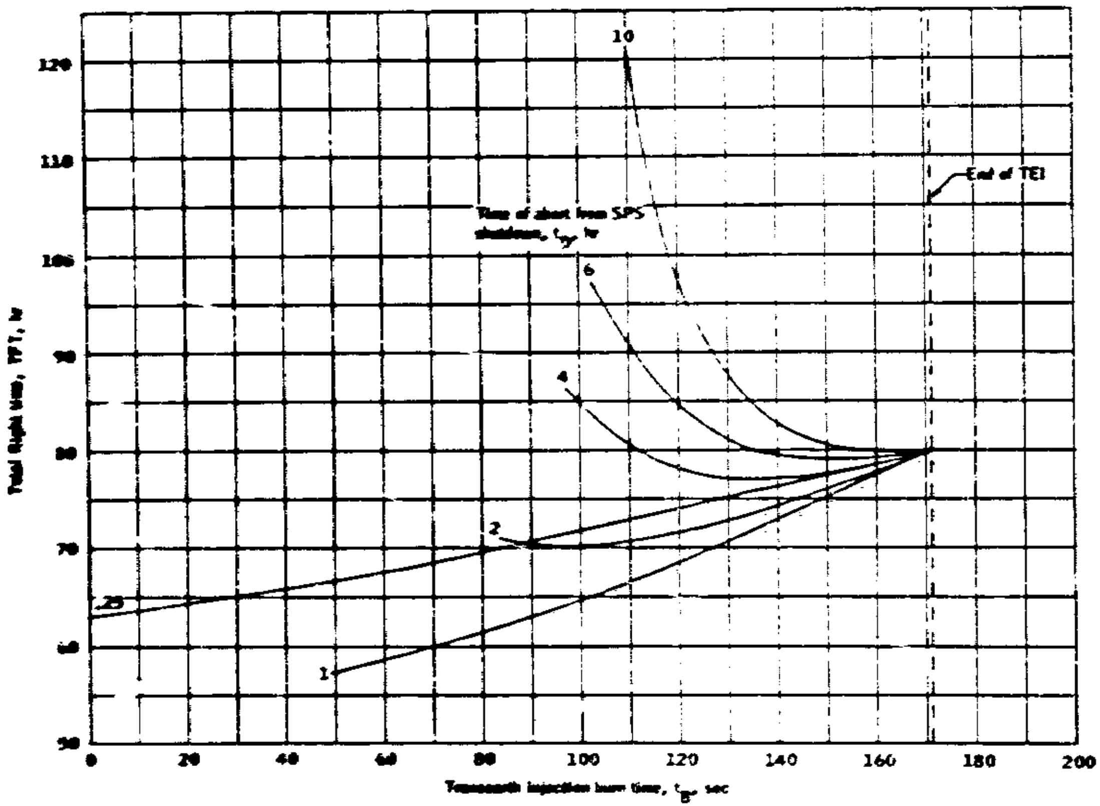


Figure 9-5.- SPS ΔV available following a premature SPS shutdown during the TEI burn.



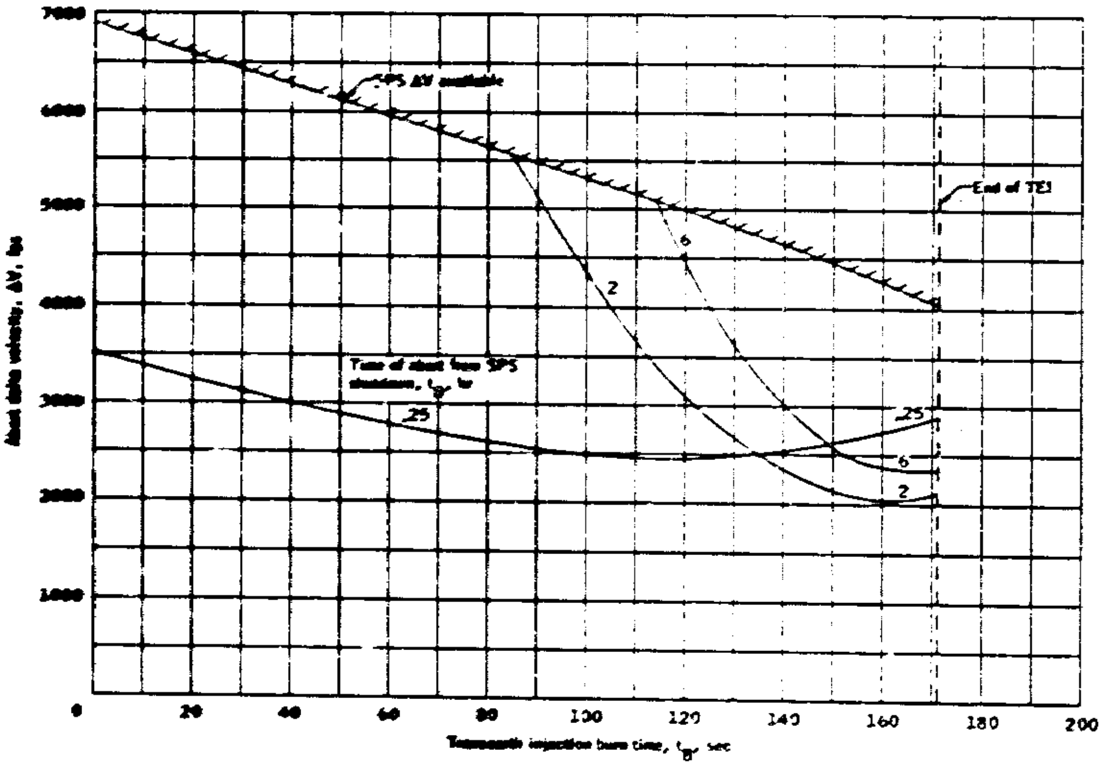
(a) Abort ΔV required as a function of TEI burn time.

Figure 9-6. - Mode I unspecified area abort analysis for various TEI burn times.



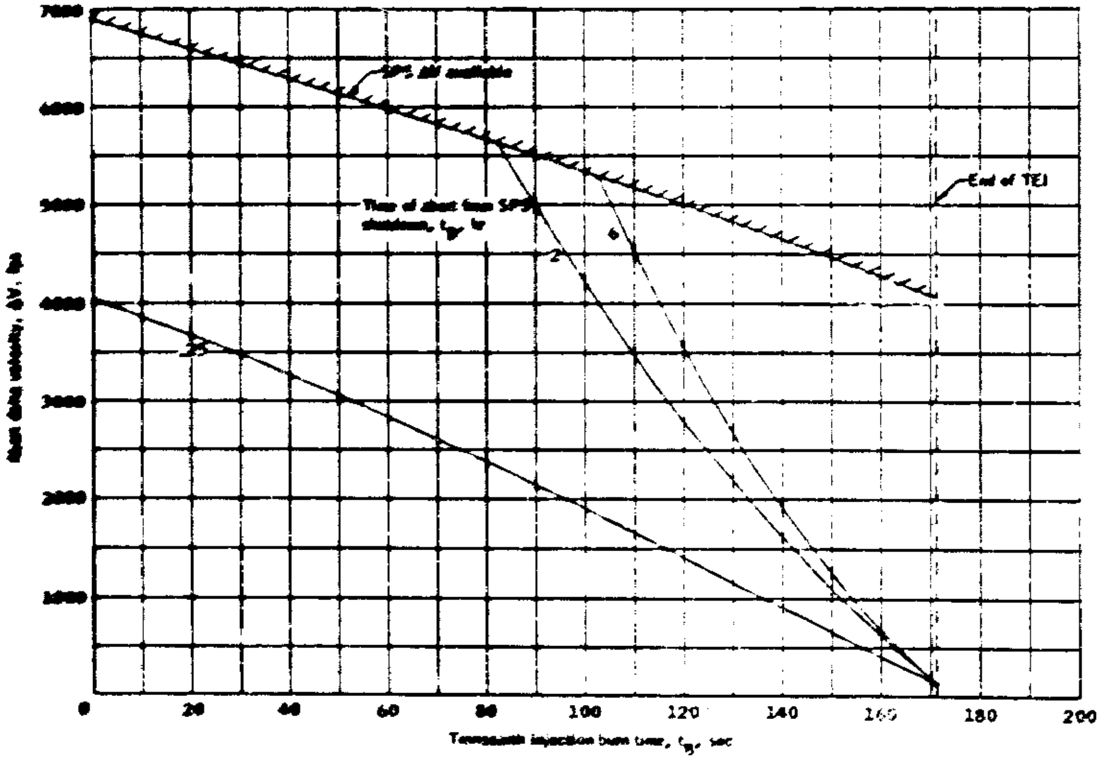
(b) Total flight time as a function of TEI burn time.

Figure 9-6.- Concluded.



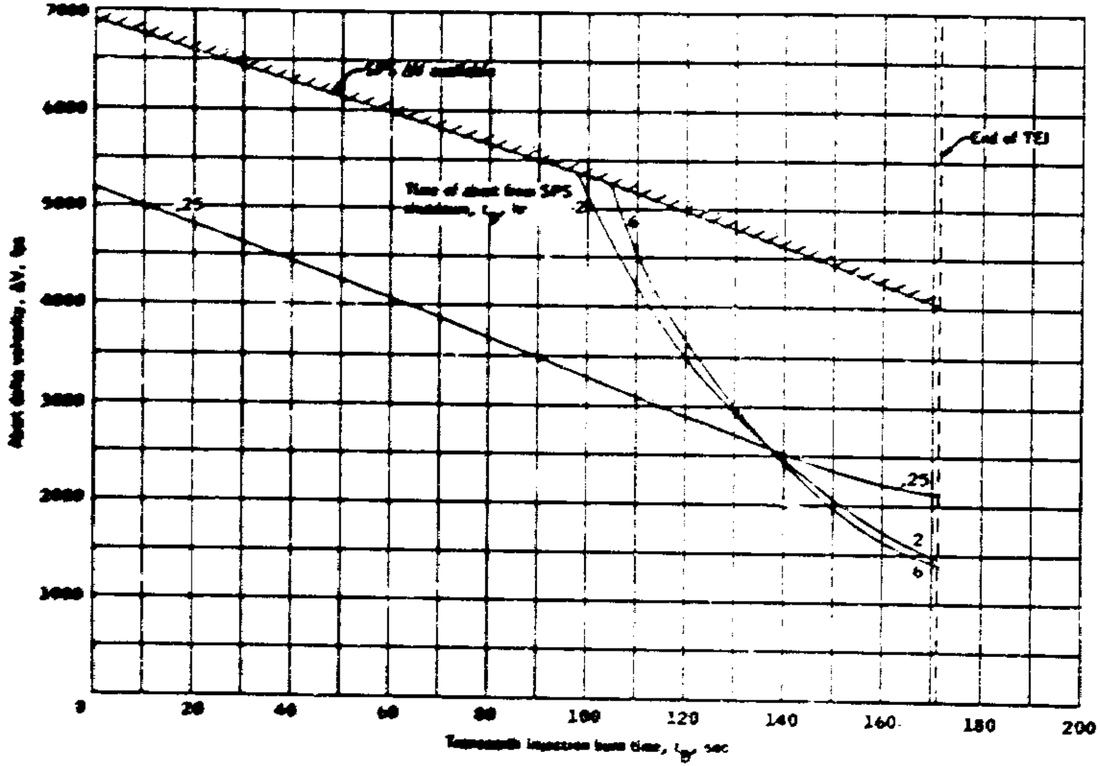
(a) Abort ΔV for MPL returns (TFT = 58 hours).

Figure 9-7.- Mode I contingency landing area abort analysis for various TEI burn times.



(b) Abort ΔV for MPL returns (TFT = 82 hours).

Figure 9-7.- Continued.



(c) Abort ΔV for MPL returns (TFT = 106 hours).

Figure 9-7.- Concluded.

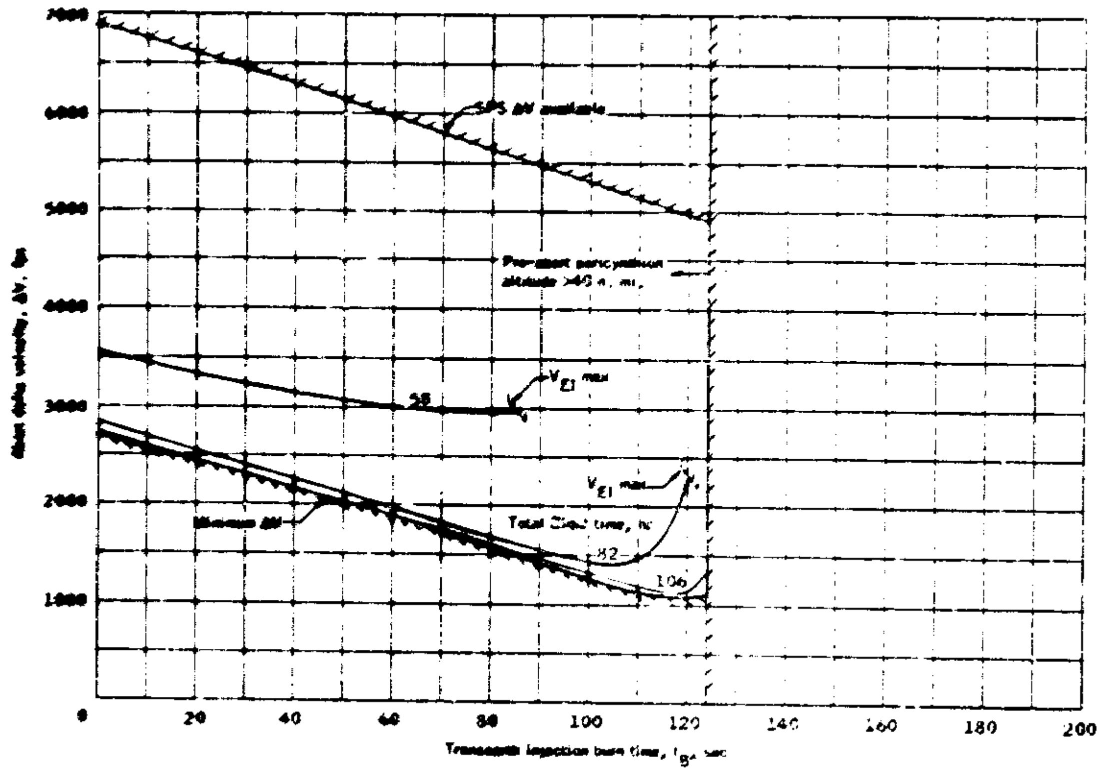
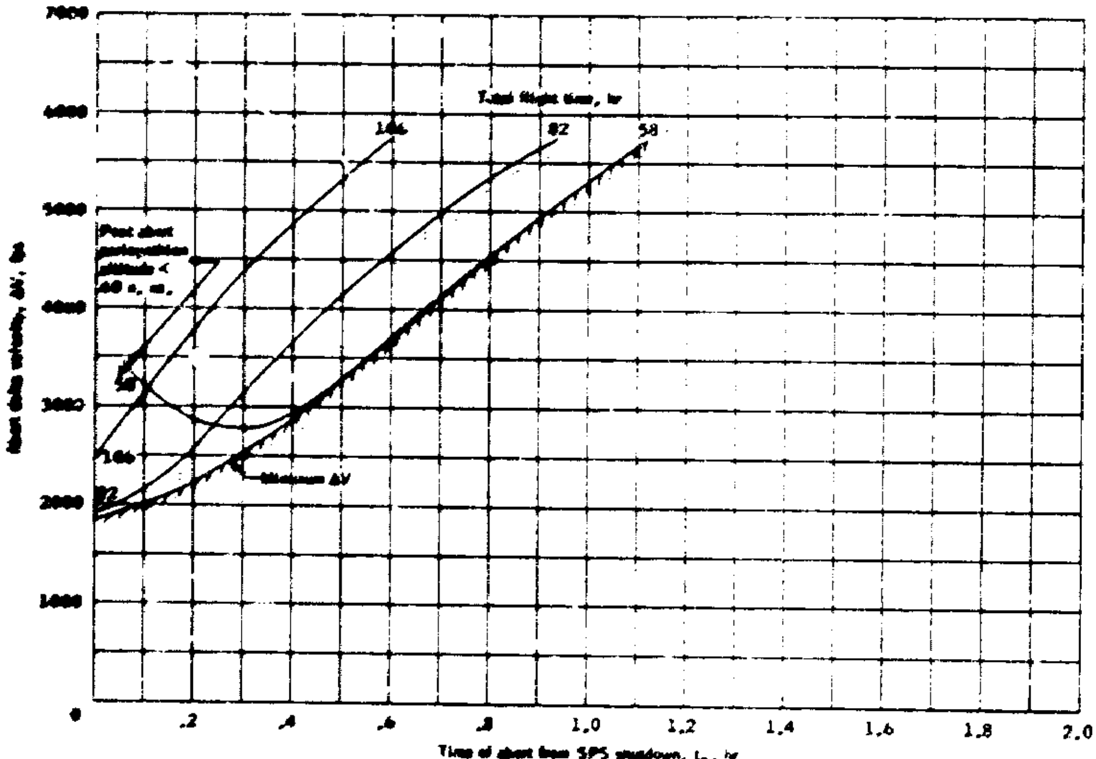
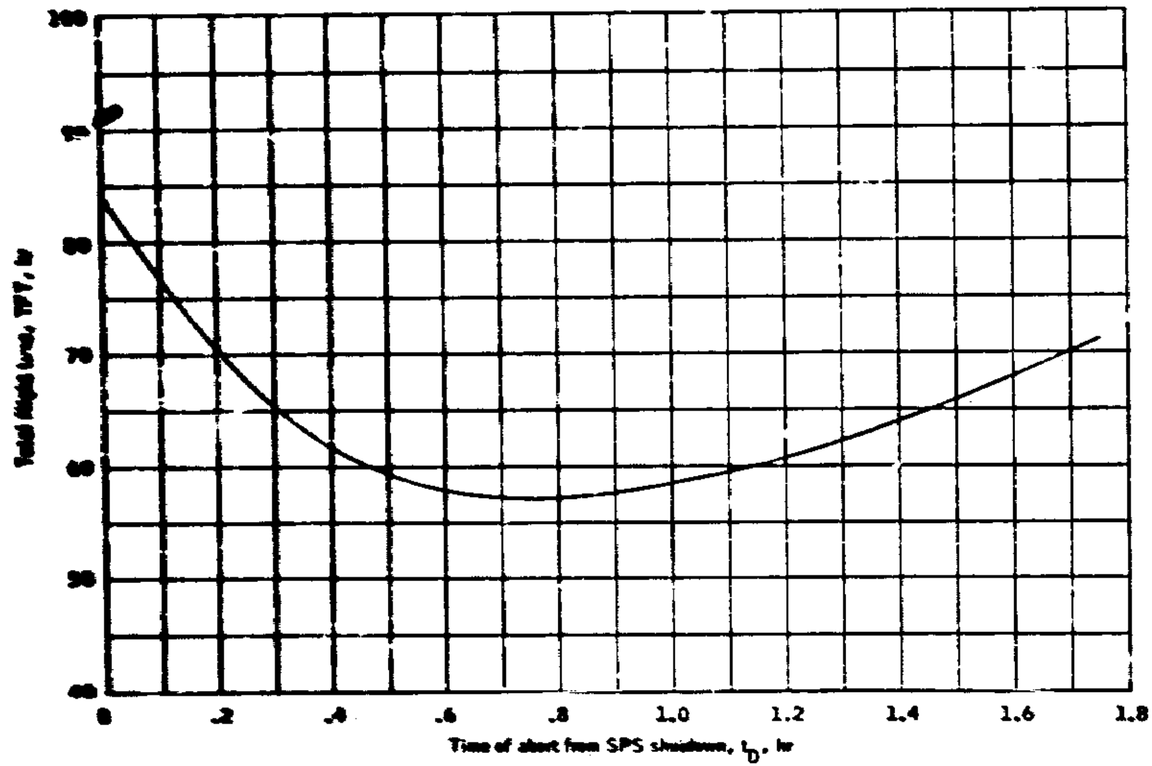


Figure 9-8.- Mode III abort analysis for various TEI burn times. Abort ΔV for MPL and FCUA returns as a function of TEI burn time.



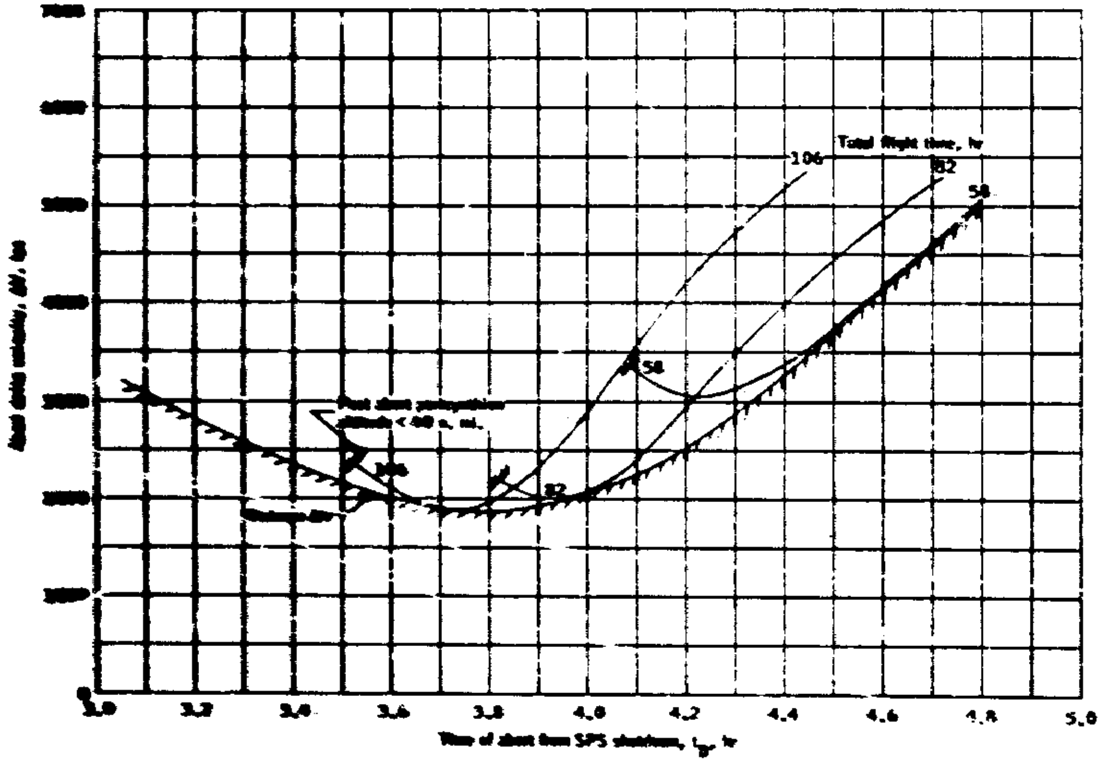
(a) Abort ΔV as a function of delay time from TEI shutdown (MPL and FCUA returns).

Figure 9-9. - Mode I abort analysis for TEI shutdown at 60 seconds.



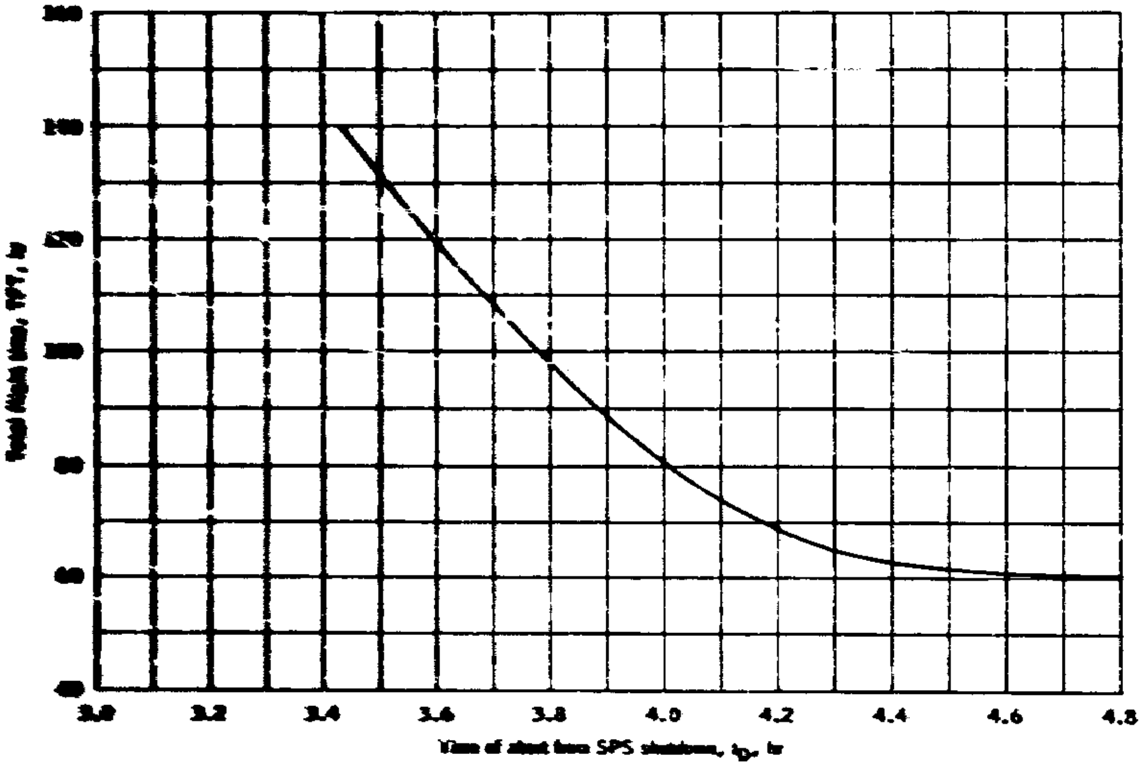
(b) Total flight time as a function of delay time from TEI shutdown for FCUA returns.

Figure 9-9.- Concluded.



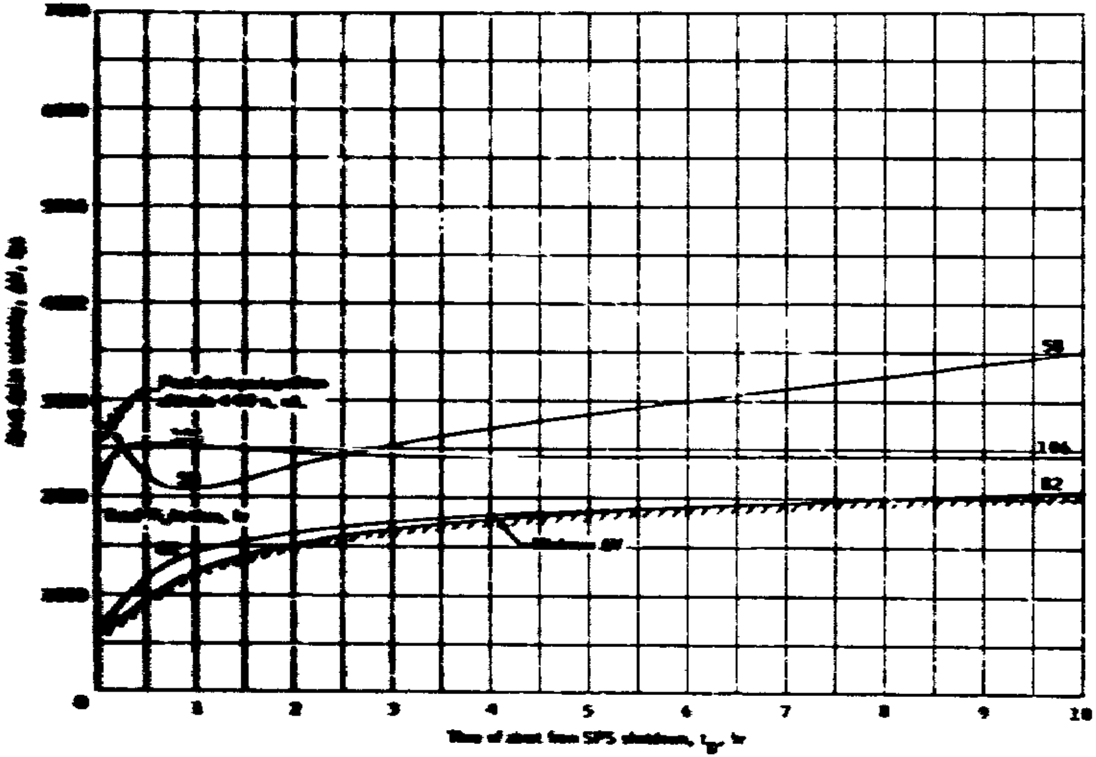
(d) Abort ΔV as a function of delay time from TEI shutdown (MPL and FCUA return).

Figure 9-36.- Mode III abort analysis for TEI shutdown at 60 seconds.



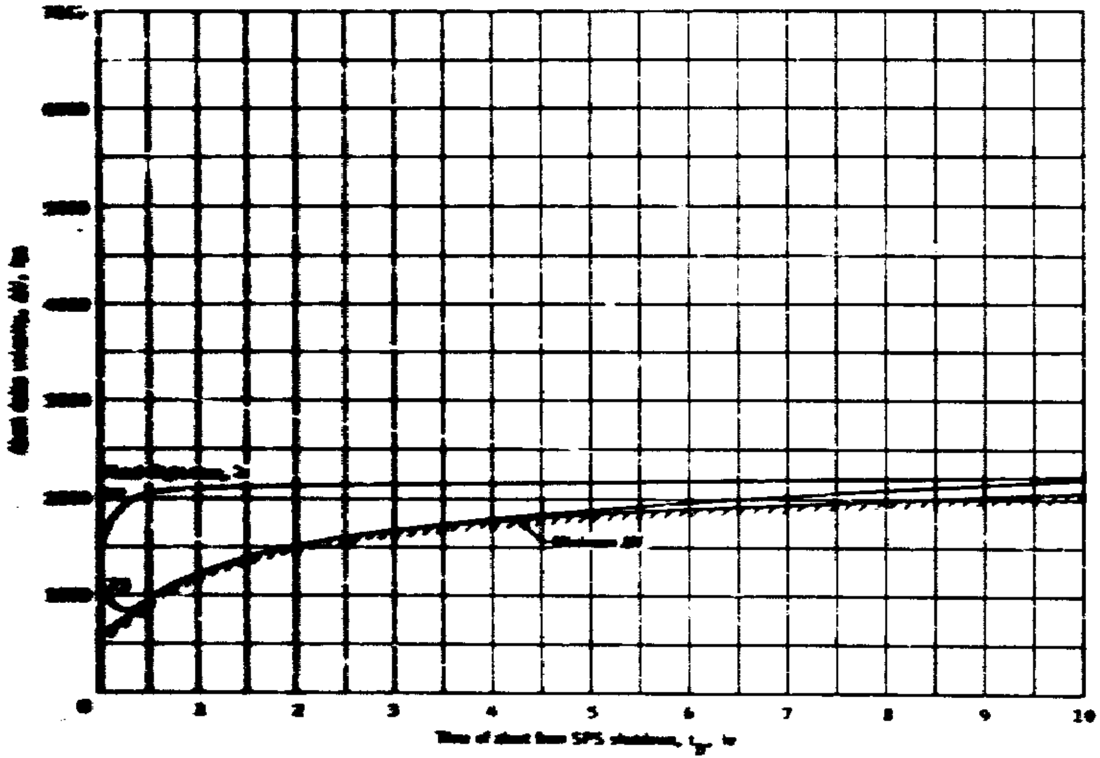
(b) Total flight time as a function of delay time from TEI shutdown for FCUA returns.

Figure 9-10.- Concluded.



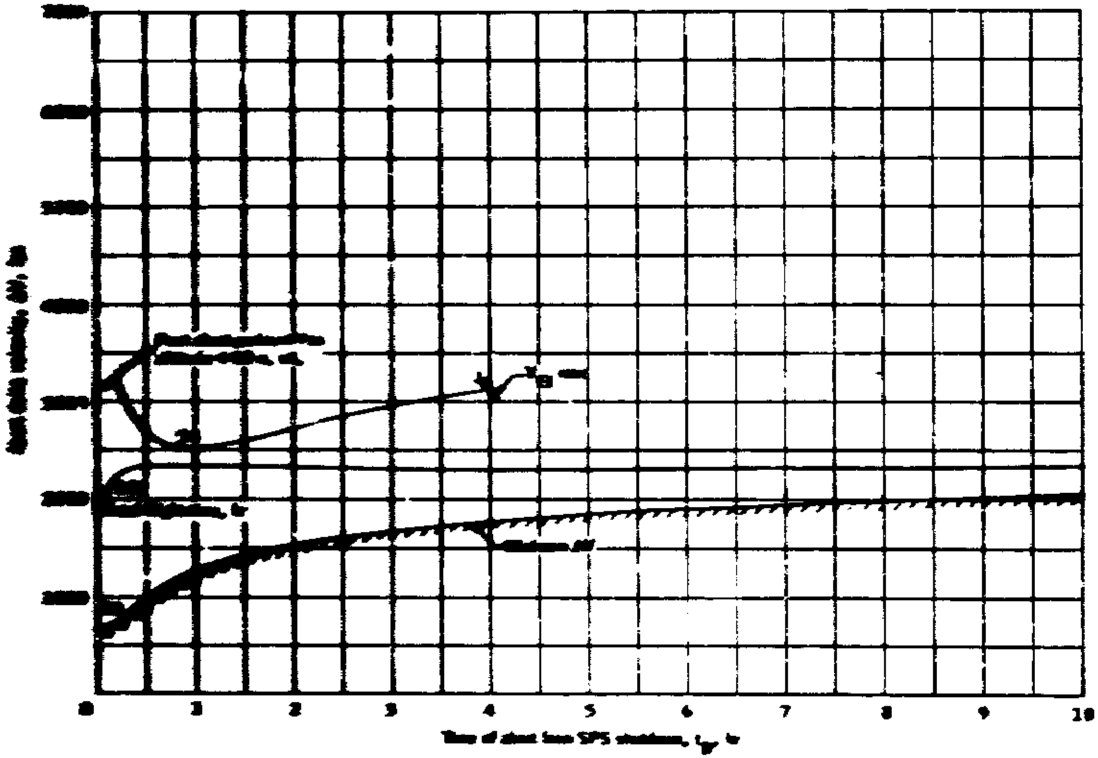
(b) [illegible] ΔV as a function of delay time from TEI shutdown ([illegible] and FCMA [illegible]).

Figure 9-11.- [illegible] abort analysis for TEI shutdown at 140 seconds.



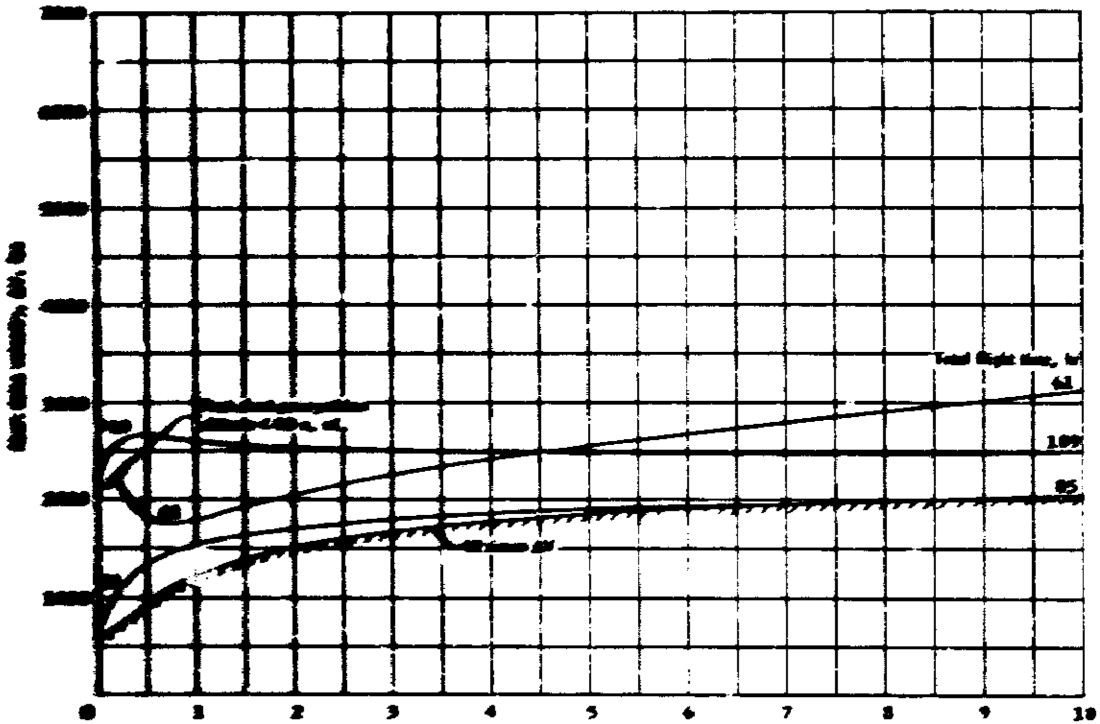
Abort ΔV as a function of delay time from LOI shutdown.

Figure 9-11.- Continued.



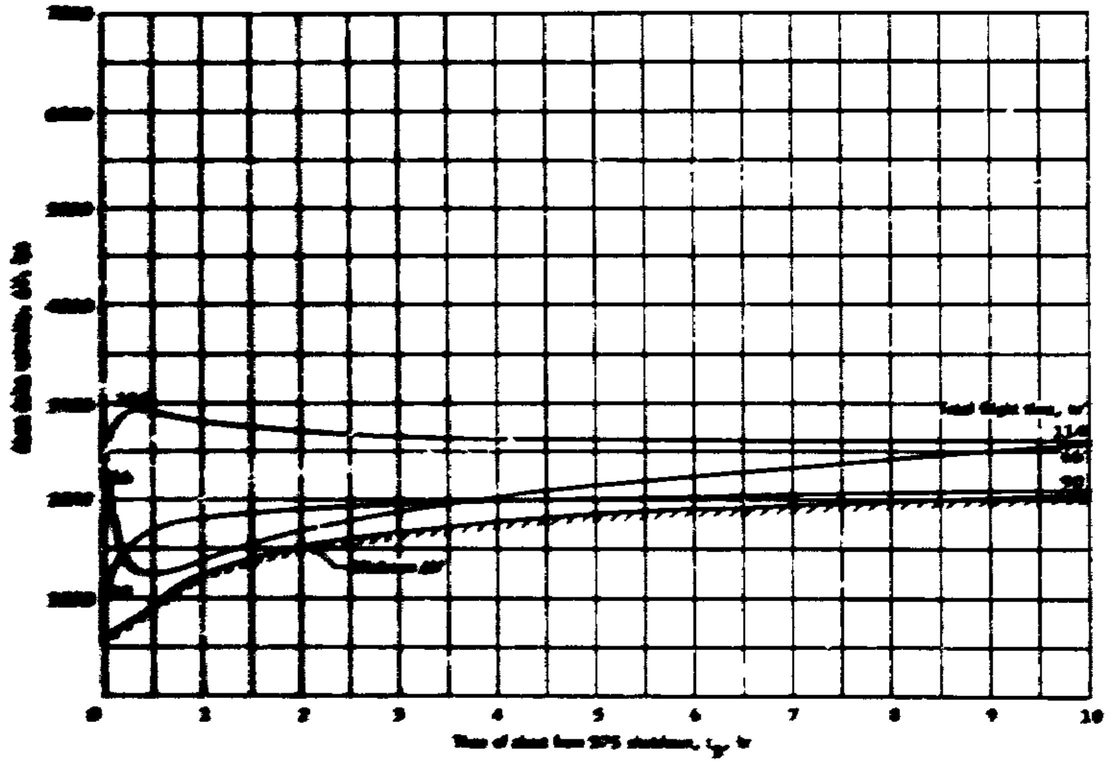
[illegible] as a function of delay time from LOI shutdown (EPL).

Figure 9-11.- Continued.



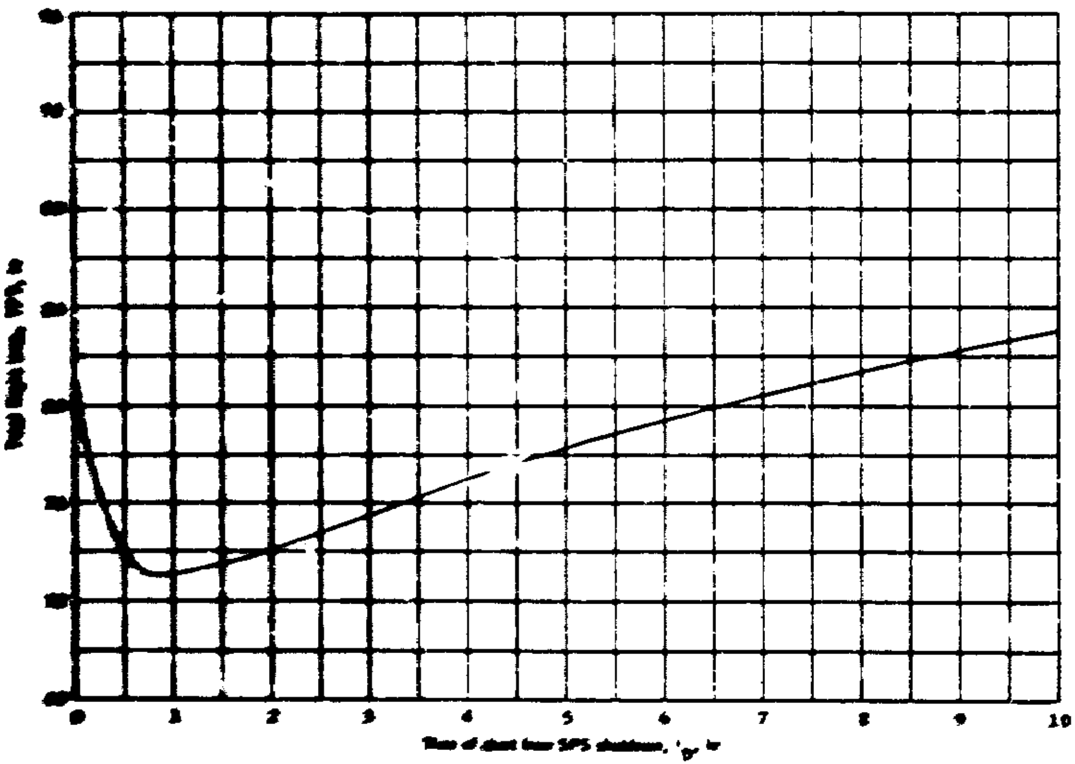
[illegible] ΔV as a function of delay time from LOI shutdown [illegible].

Figure 9-11.- Continued.



[illegible] as a function of delay time from [illegible] shutdown [illegible]

Figure 9-11.- Continued.



[illegible]

Figure 9-11.- Concluded.

10.0 CONCLUSIONS

A continuous method of returning the flight crew safely to earth for the Apollo 8 mission - with or without ground control help - has been defined. The rationale and supporting data are contained in this operational abort plan. These supporting data consist primarily of (1) maneuver monitoring techniques and limits used to protect against known constraints, and (2) abort trajectory data produced by computer simulations of the recommended abort procedures identified in figure 2-1.

10.1 Launch Phase

Although continuous suborbital abort capability is provided during the launch phase, the primary objective, in addition to crew safety, is to continue to orbit. This can be accomplished when early S-IV staging capability becomes available, when the S-II is burning, and when SPS COI capability becomes available during the first S-IVB burn.

10.2 TLI and Translunar Coast

The postabort trajectories resulting from early S-IVB shutdown and the 10-minute abort procedure may result in land landings. Based on the expected inaccuracies in the attitude alignment for the 10-minute abort, a MCC will be required for aborts occurring after about 200 seconds into TLI.

All return-to-earth maneuvers from the translunar coast mission phase are initiated at an attitude which causes the earth to appear in the commander's window.

The SM RCS provides a backup capability for returning the SC to earth following premature S-IVB shutdowns during TLI for most of the TLI burn. Analysis is currently being conducted by the Contingency Analysis Section to determine the limitations on RCS aborts from the nominal and dispersed TLI burns. Available information is contained in appendix B.

10.3 LOI and Lunar Orbit

A complete return-to-earth capability exists for premature shutdowns during the LOI burn as well as the nominal lunar orbit phase. Manual LOI shutdowns which occur due to serious SPS problems require a [illegible] chart for abort targeting. Inadvertent automatic shutdowns require RTCC solutions if an abort decision is made. If communications are lost

and neither of the above aborts were initiated, an onboard return-to-earth targeting capability exists.

10.3 TEI and Transearth Coast

Shutdowns during the TEI burn can occur only due to inadvertent automatic shutdown since manual shutdowns are not required. Immediate SPS restarts will be initiated. The only time an abort is required is when an immediate SPS restart is not possible, which implies serious SPS problems. Since communications failures would also have to occur in addition to very serious SPS problems, backup crew charts are not warranted.

During the TEC, an abort can shorten the return time if CSM system problems occur. The primary constraint is the maximum entry velocity possible.

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APPENDIX A

INPUT CONSTANTS

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TABLE A-I.- CONSTANTS USED IN TRAJECTORY SIMULATIONS

(a) Launch phase

Fully loaded CSM weight, lb	63 571.0
Beginning of Mission CM entry weight, lb.	12 153.0
SPS thrust, lb	20 500
SPS specific impulse, sec	314.1
SPS fuel weight flow, lb/sec	65.26

(b) TLI and TLC phase

SC weight, lb	63 741.
SPS thrust, lb	20 500
SPS flow rate, lb/sec .	65.266
RCS thrust (1), lb . . .	96.00
RCS flow rate, lb/sec .	.381
Pitch trim angle, deg .	-1.65
Yaw trim angle, deg . .	+1.27
L/D	.295

(c) LOI, lunar orbit and TEI phase

SC weight at LOI ignition, lb . .	62 629.
SPS thrust, lb	20 500
SPS I_{sp}, sec	314.1
Pitch trim angle, deg	-3.215
Yaw trim angle, deg	2.22
L/D	.25

TABLE A-II.- AERODYNAMICS

[X_{CG} = 1040.83 in; Y_{CG} = -0.20 in; Z_{CG} = 5.86 in; weight = 12153.0 lb; and bank angle bias = -1.95°]

Mach number, M, n.d.	Trim angle of attack, α_T, deg	Lift coefficient, C_L, n.d.	Drag coefficient, C_D, n.d.	Lift-to-drag ratio, L/D, n.d.
0.20	170.88	0.23378	0.82537	0.28324
0.40	167.5	0.23704	0.85430	0.27746
0.70	164.82	0.25831	0.98808	0.26143
0.90	162.14	0.31453	1.06871	0.29430
1.10	155.46	0.48459	1.17674	0.41181
1.20	155.64	0.47056	1.16219	0.40489
1.35	154.51	0.55366	1.28485	0.43091
1.65	153.69	0.54381	1.27166	0.42764
2.00	153.63	0.52800	1.28161	0.41199
2.40	154.16	0.50245	1.25127	0.40155
3.00	154.63	0.47418	1.22719	0.38640
4.00	156.56	0.43658	1.22294	0.35699
10.00	157.2	0.42387	1.23297	0.34378
29.50	160.5	0.38183	1.29745	0.29429

APPENDIX B

RCS ABORT STUDIES

APPENDIX B

RCS ABORT STUDY

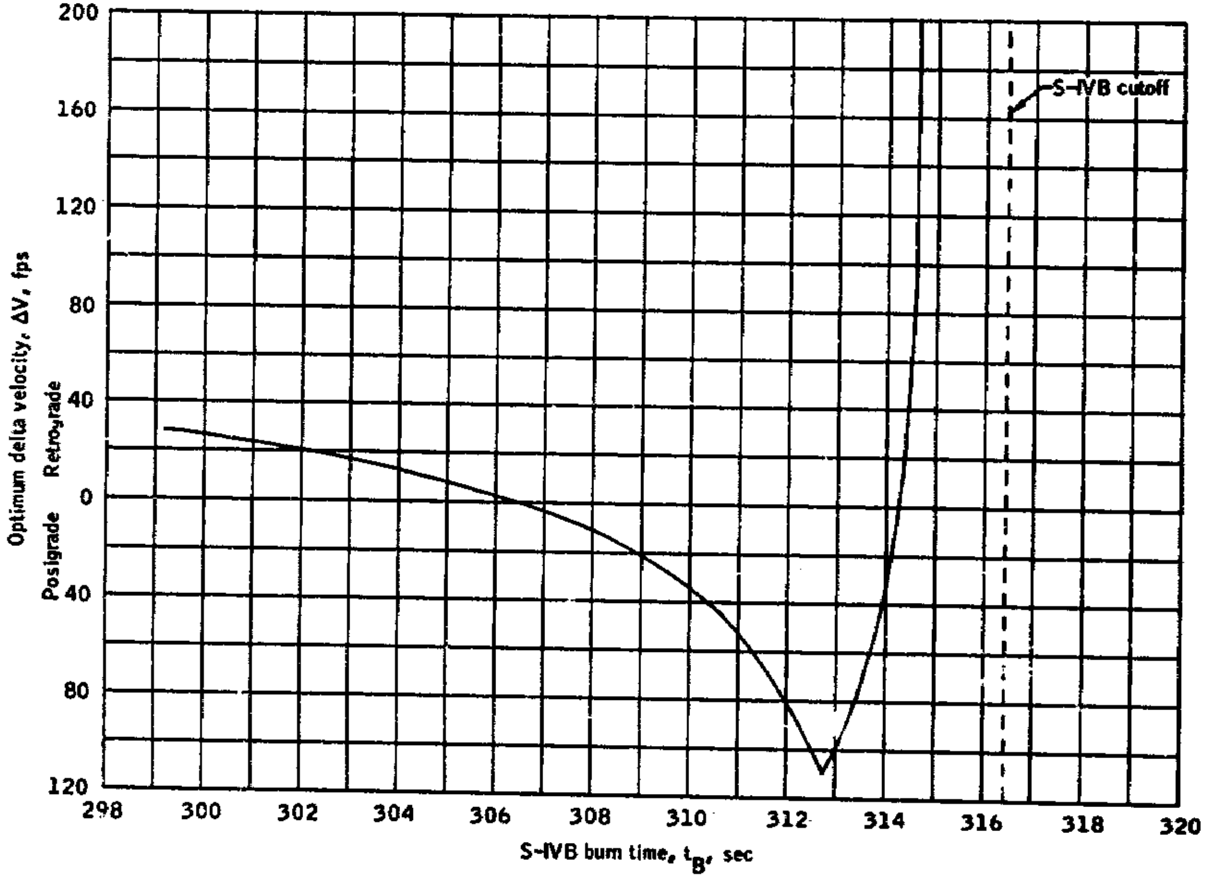
The backup propulsion system for aborts on Apollo 8 is the SM RCS, which delivers about 376 lb (four thrusters firing) of thrust in a steady state inertial attitude thrusting mode. The SM RCS provides a return-to-earth capability following premature S-IVB shutdowns during TLI for a major portion of the TLI burn.

This minimum fuel abort analysis was not constrained to any specific landing area. The study covers approximately the last 16 seconds of the S-IVB burn, which is the most critical period due to rapidly changing abort ΔV requirements and perturbations due to the moon's gravitational influence.

The optimum place to perform a minimum fuel abort is near apogee of the preabort trajectory. All aborts considered in this study were performed at or near apogee.

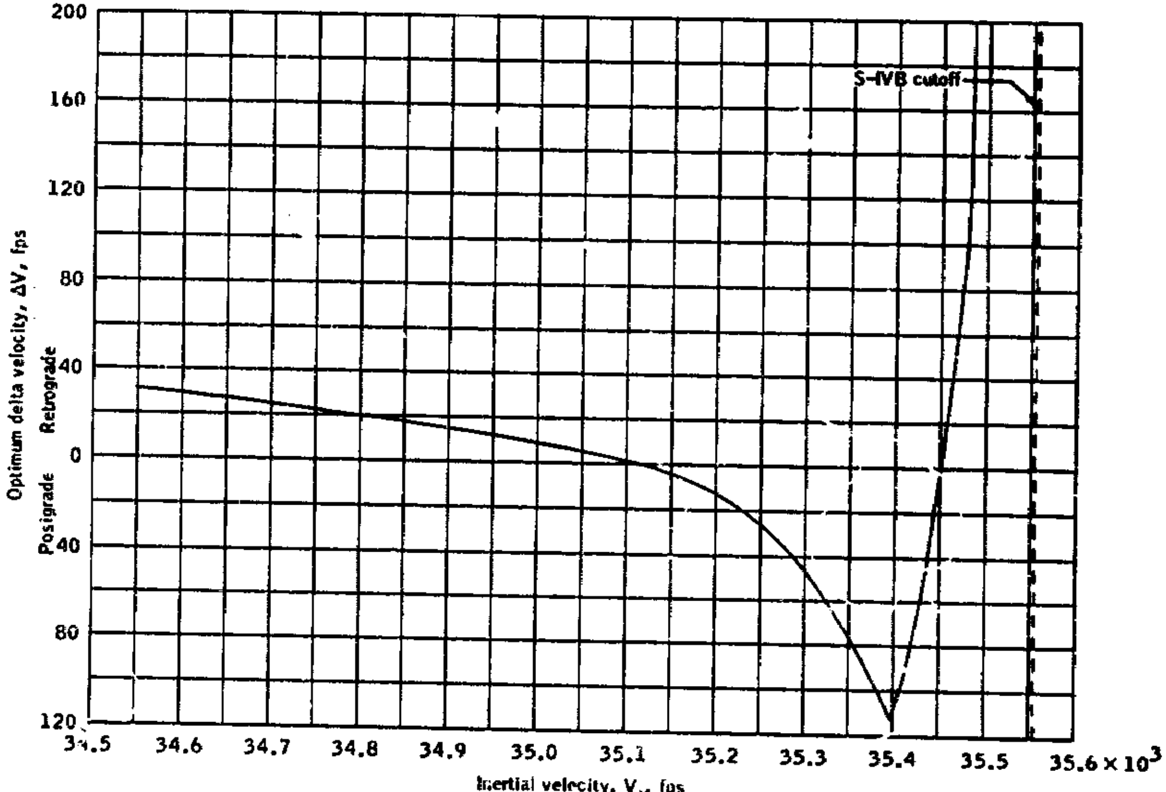
Figure B-1 shows the ΔV needed for a direct return to earth. The ΔV is shown both as a function of S-IVB burn time and inertial velocity at S-IVB shutdown. RCS aborts performed for S-IVB shutdowns prior to 306.5 seconds are performed in a retrograde attitude. Due to the moon's perturbations, the RCS abort must be performed in the posigrade attitude for S-IVB burn times of 306.5 to 314.3 seconds. The reason is that the actual perigee of the trajectory in that region becomes less than the radius of the earth due to the moon's effect. For approximately the last 2 seconds of the S-IVB burn, the perigee rapidly increases and the ΔV required for aborts becomes very large. The total available SM RCS ΔV available for aborts following early S-IVB shutdown is approximately 160 fps. During the last 1.8 seconds of the S-IVB burn, the perturbative effect from the moon is so large that the RCS does not have the capability to return the SC safely directly to the earth, although a circumlunar midcourse may be possible. (See ref. 27.)

Figure B-2 shows the time from S-IVB shutdown to apogee and from shutdown to landing for RCS aborts at apogee (TFT). These times are shown as a function of inertial velocity at the time of S-IVB shutdown.



(a) S-IVB burn time versus optimum delta velocity.

Figure B-1.- Delta velocity required for RCS aborts at apogee.



(b) Inertial velocity versus optimum delta velocity.

Figure B-1.- Concluded.

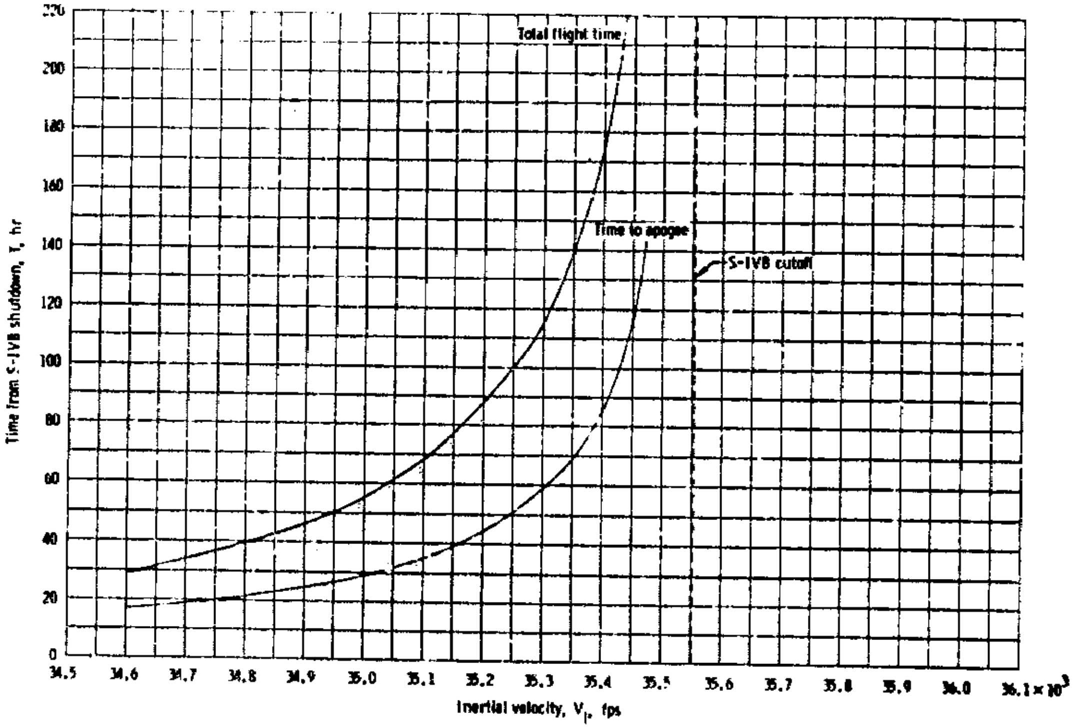


Figure B-2.- Time to apogee and landing for premature S-IVB shutdown using the RCS for aborts.

END

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